Perception of Vocal Effort: the Influence of Vocal Fundamental Frequency and Vocal Intensity

by

ROBERT LOUIS ILES

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
1973

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. G. Paul Moore for his encouragement, advice and assistance to the writer both in the progress of this study and during the course of the writer's graduate career at the University of Florida.

The members of the writer's supervisory committee, Drs. Hutchinson, Nielsen, Ramey and Yost, are due special thanks for their support, patience and constructive suggestions toward the writer's course of study as well as those specifically relevant to this study.

Particular gratitude is expressed to Wayne Harrington for the design of special electronic circuitry and for his assistance generally with the electronic equipment without which the study could not have been accomplished. Thanks are tendered also to the staff of the Communication Sciences Laboratory Electronics Shop, Robert Idzikowski, Russell Pierce and David Campbell, for assistances too frequent and numerous to list.

The author acknowledges an enormous debt to his lovely wife, Mallory, for her encouragement, love and faith and, especially, for her patience during a trying but rewarding period of time.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ii

LIST OF TABLES iv

LIST OF FIGURES viii

ABSTRACT x

CHAPTER

I INTRODUCTION 1
    Purpose 13

II PROCEDURE 14

III RESULTS AND DISCUSSION 35
    A posteriori Comparisons 37
    Main Effects 81
    Stimuli Manipulations 95
    Discussion of the Research Questions 118

IV SUMMARY AND CONCLUSIONS 127

APPENDIX A 132

APPENDIX B 137

BIBLIOGRAPHY 138

BIOGRAPHICAL SKETCH 141

LIST OF TABLES

Table Page

1. Production Stimuli 15

2. The Experimental Stimuli 25

3. TDH-49 Earphone Calibration Values 30

4. Analysis of Variance Summary Table 36

5. Key to Factor Coding 38

6. Order/Frequency/Intensity Interaction-- Mean Log Judgement Values 40

7. Intensity/Frequency/Order Factor Ordering, Low to High . . . 42

8. Significant *a posteriori* Test Results--Order/ Frequency/Intensity Interaction (5% Level of Significance): Order Relationships 43

9. Order/Intensity/Frequency Factor Ordering, Low to High . . . 45

10. Significant *a posteriori* Test Results--Order/ Frequency/Intensity Interaction (5% Level of Significance): Frequency Relationships 46

11. Order/Frequency/Intensity Factor Ordering, Low to High . . . 47

12. Significant *a posteriori* Test Results--Order/ Frequency/Intensity Interaction (5% Level of Significance): Intensity Relationships 48

13. Task/Frequency/Intensity Interaction-- Mean Log Judgement Values 50

14. Intensity/Frequency/Task Factor Ordering, Low to High . . . 51

15. Significant *a posteriori* Test Results--Task/ Frequency/Intensity Interaction (5% Level of Significance): Task Relationships 52

16. Task/Intensity/Frequency Factor Ordering, Low to High . . . 54

Table Page

17. Significant a posteriori Test Results--Task/Frequency/Intensity Interaction (5% Level of Significance): Frequency Relationships 55

18. Task/Frequency/Intensity Factor Ordering, Low to High . . . 56

19. Significant a posteriori Test Results--Task/Frequency/Intensity Interaction (5% Level of Significance): Intensity Relationships 57

20. Task/Order/Intensity Interaction--Mean Log Judgement Values 58

21. Intensity/Order/Task Factor Ordering, Low to High 59

22. Significant a posteriori Test Results--Task/Order/Intensity Interaction (5% Level of Significance): Task Relationships 60

23. Task/Intensity/Order Factor Ordering, Low to High 61

24. Significant a posteriori Test Results--Task/Order/Intensity Interaction (5% Level of Significance): Order Relationships 62

25. Task/Order/Intensity Factor Ordering, Low to High 63

26. Significant a posteriori Test Results--Task/Order/Intensity Interaction (5% Level of Significance): Intensity Relationships 64

27. Frequency/Intensity Interaction--Mean Log Judgement Values 65

28. Frequency/Intensity Factor Ordering, Low to High 66

29. Significant a posteriori Test Results--Frequency/Intensity Interaction (5% Level of Significance) 67

30. Task/Intensity Interaction--Mean Log Judgement Values 69

31. Task/Intensity Factor Ordering, Low to High 70

32. Significant a posteriori Test Results--Task/Intensity Interaction (5% Level of Significance) 71

33. Order/Frequency Interaction--Mean Log Judgement Values 72

34. Order/Frequency Factor Ordering, Low to High 73

Table Page

35. Significant *a posteriori* Test Results--Order/Frequency Interaction (5% Level of Significance) 74

36. Task/Frequency Interaction--Mean Log Judgement Values 75

37. Task/Frequency Factor Ordering, Low to High 76

38. Significant *a posteriori* Test Results--Task/Frequency Interaction (5% Level of Significance) 77

39. Mean Log Judgements for Task 78

40. Mean Log Judgements for Order 78

41. Mean Log Judgements for Frequency 78

42. Mean Log Judgements for Intensity 78

43. Factor Ordering, Low to High 79

44. Significant *a posteriori* Test Results--Intensity (5% Level of Significance) 80

45. Significant *a posteriori* Test Results--Frequency (5% Level of Significance) 80

46. Significant *a posteriori* Test Results--Order (5% Level of Significance) 80

47. Analysis of Variance Summary Table, RM 97

48. Analysis of Variance Summary Table, MR 98

49. Analysis of Variance Summary Table, MM 99

50. Analysis of Variance Summary Table, AA 100

51. Summary of Significant Effects, All Conditions 101

52. Mean Log Judgements for Intensity, All Conditions 102

53. Mean Log Judgements for Frequency, All Conditions 103

54. Mean Log Judgements for Order, All Conditions 104

55. Mean Log Judgements for Task, All Conditions 105

56. Task/Intensity Interaction--Mean Log Judgement Values, All Conditions 111

Table Page

57. Task/Frequency Interaction--Mean Log Judgement Values, All Conditions 116

LIST OF FIGURES

Figure Page

1. Recording Equipment 19

2. Stimulus Preparation 22

3. The Experimental Design 33

4. Intensity Main Effect 83

5. Task/Intensity Interaction by Task 84

6. Task 3/Frequency/Intensity Interaction by Frequency 86

7. Frequency Main Effect 87

8. Task/Frequency Interaction by Task 88

9. Frequency/Intensity Interaction by Intensity 89

10. Order Main Effect 91

11. Task Main Effect 92

12. Task 1/Frequency/Intensity Interaction by Intensity 94

13. Intensity Main Effect, All Conditions 106

14. Frequency Main Effect, All Conditions 107

15. Order Main Effect, All Conditions 108

16. Task Main Effect, All Conditions 109

17. Task 1/Intensity Interaction, All Conditions 112

18. Task 2/Intensity Interaction, All Conditions 113

19. Task 3/Intensity Interaction, All Conditions 114

20. Task 3/Frequency Interaction, All Conditions 117

21. Listener Loudness vs SPL and Listener Effort vs SPL Slopes: All Conditions 120

Figure Page

22. Speaker Loudness vs SPL Slopes: All Studies 121

23. Speaker Loudness vs SPL Slopes by Fundamental Frequency . . 122

24. Listener Loudness vs SPL by Fundamental Frequency 123

25. Listener Loudness vs SPL Slopes: All Studies 124

26. Listener Loudness vs SPL Slopes: All Manipulation Studies 126

Abstract of Dissertation Presented to the
Graduate Council of the University of Florida in Partial Fulfillment
of the Requirements for the Degree of Doctor of Philosophy

PERCEPTION OF VOCAL EFFORT: THE INFLUENCE OF VOCAL FUNDAMENTAL FREQUENCY AND VOCAL INTENSITY

by

Robert Louis Iles

August, 1973

Chairman: G. Paul Moore
Major Department: Speech

Vocal effort, loudness and pitch judgements were obtained from 12 listeners in the present study in an attempt to determine (1) whether the percept of vocal effort was different from percepts of loudness and pitch and (2) what contribution (a) fundamental frequency (f_o) and (b) intensity made to these percepts. One adult male speaker produced the vowel /ɛ/ at five f_os at each of eight intensities. The stimuli were then manipulated to produce (1) five f_os and eight intensities, (2) five f_os and one intensity, (3) one f_o and eight intensities, (4) one f_o and one intensity and (5) five artificial f_os and eight artificial intensities. All listeners made judgements of each percept with two listeners assigned to each of six presentation-of-task orderings. The results obtained from the analyses indicated that listeners did tend mainly to equate loudness and effort but that the stimulus frequency influenced their judgements. Key points are summarized below.

Both effort and loudness judgements were found to differ from pitch judgements and all three percepts were found to be influenced by both f_o and intensity. Pitch judgements, as could be expected, were primarily mandated by f_o, but not exclusively. Loudness and effort judgements were found to differ at the low intensity-high f_o levels although intensity appeared to be the prime contributor to judgements of both effort and loudness. The interaction between frequency and intensity prohibits a more definitive statement. An order-of-task-presentation effect was noted which cannot presently be explained by the author, but which must be considered in future research into this area. Effort judgements similar to those in the original stimuli block were obtained from the artificial stimuli condition although values at the lower intensity levels were less extreme than with the real stimuli (i.e., real f_o by real intensity with presumed real effort levels), suggesting that the constant effort factor of the artificial stimuli did subtly influence listener judgements.

It appears that effort judgements generally do in a very real fashion follow intensity changes as do loudness judgements but differ in degree in that the effort judgements are less depressed by decreased intensity than are loudness judgements at low intensity levels. The effort judgements are influenced to a lesser degree by f_o, but this effect does not appear to be separable from the intensity effect.

Based on results from the artificial stimuli condition, it appears that there is a vocal effort factor perceivable in the vocal signal that tends to moderate the intensity effect on both loudness and effort judgements and, to a degree, to somewhat mitigate intensity influence on pitch judgements. The author considers that vocal effort exists as a real percept, but not at an obvious or easily studied level.

I

INTRODUCTION

The concept of vocal effort has been used by those attempting to deal with the human voice or speech. Clinicians often use the term in a pathological sense inferring that only minimal effort is utilized in the normal voice. A corollary is found in descriptions of vocalists attaining a particular--usually high--note only "with a great effort" or by "straining." "Effortless" normally carries a positive and "effortful" a negative connotation.

There is a dualism to the term effort, however, which must be recognized: descriptions deal with a percept while the usage of "effort" for "try" infers a parameter of force in the mechanical sense. Whether these two concepts are compatible is not known. Since this dualism does exist, the literature pertinent to vocal effort is presented below as it relates to (1) production or (2) percept.

Wright and Colton (1971) reported that Ss' magnitude estimates and magnitude productions were remarkably similar in plotted form (effort level vs. Sound Pressure Level or SPL and effort level vs. Frequency Level or FL in semitones). Their Ss produced various effort levels, assigning a numerical value to each level immediately after production. Subsequently each S was required to generate an effort level appropriate to each of five numbers selected to sample the range of magnitudes assigned by S during the estimation procedure. As noted, the estimation and production data closely agreed (cf. Hellman and Zwislocki, 1963). The authors also reported obtaining a single estimate from each S of his minimum, maximum and most comfortable effort levels. Analysis showed that these estimates provided a good approximation to the function for each S, with effort described as a power function of SPL and FL, changing slope at the most comfortable level.

In a later report, Wright and Colton (1972) presented data for a single S in which S made estimates and, later, productions to a sampling of these estimates, with a 1000 Hz tone. Again, the estimate-production correspondence was high.

In a study dealing with vocal effort and intraoral air pressure, Colton and Brown (1972) utilized the above-noted approximation to sample Ss' minimum, most comfortable and maximum vocal effort levels. They found vocal effort to be a power function of intraoral air pressure, noting again the slope change at the most comfortable level.

Also utilizing this reported production consistency, Allen (1972) requested her Ss to maintain a "constant comfortable effort level" for sample production. Iles (1972) instructed his Ss to "speak normally, at a conversational level, and try to repeat the sentence in the same manner as originally read," assuming an approximate equation of vocal effort level from S to S and from repetition to repetition. Brown (1972) instructed his Ss to produce samples "in a comfortable manner" and to "try to say them the same way each time" where replication occurred, again with the presumption of equality of vocal effort level across Ss and replications.

Lehiste and Peterson (1959) provided another view of vocal effort. They noted that a large compilation of recorded vowel samples from a single speaker appeared "to be equally loud" although individual samples were as much as 7.7 dB apart in SPL. They then had a speaker record another list of randomized vowel samples at equal VU meter levels and reported that "some vowels required considerably greater effort than others."

The validity of equating vocal effort to loudness (or SPL) as noted by Lehiste and Peterson (1959) was questioned by Lane, Catania and Stevens (1961). They queried whether a person, in judging his autophonic productions, depended on his perception of loudness or "some other variable, such as muscular effort." To attempt to resolve this issue they had S generate a sustained /ɑ/ at "medium level" and assigned the number 10 to this production. S was then asked to produce a series of values (magnitudes) in irregular order including the 10 value and values both lesser and greater than 10. In addition to these production estimates, S was required to produce particular phonational levels predetermined by the experimenters but unknown to S (S achieved a VU meter level on a variously-attenuated and partially-obscured meter face). When S attained the proper level and remained stable within 3 dB for two seconds, the experimenters signaled a stop and S then gave a numerical estimate of his production (based on a medium level assigned the value of 10). The two sets of data obtained, those from production and those from estimation, contained "systematic biases that are to some extent complementary" and the authors therefore combined the two and derived a power function with autophonic level (AL) having a slope (exponent) of 1.1 (to a first approximation) when plotted against SPL. They interpreted the discrepancy between this noted 1.1 slope and the accepted 0.6 slope relating loudness to SPL (Stevens, 1955) as establishing that loudness is not S's sole criterion for AL.

Warren (1962) disputed the findings of Lane, Catania and Stevens (1961) and reported his findings from a study wherein S generated productions of /ɑ/, /ʃ/ and a pitch-pipe note, first at a "moderate level" and immediately thereafter at a "half-level." SPL readings of these productions were taken and the various productions were found not to statistically differ. Warren concluded from these data based on sound-energy productions "involving different sets of muscles and different manners of setting air in vibration" that S's AL judgements were based solely on loudness. Slope values were obtained for /ɑ/ and /ʃ/ of 0.84 and for the pitch-pipe, 0.75.

Lane (1963) presented AL data derived from congenitally deaf Ss showing a slope of 1.3 which compares favorably with his (1962) data from normal Ss vocalizing with sidetone present (1.2) and with masking (1.3). The congenitally deaf, as Lane points out, "have never had auditory cues available while vocalizing" and cannot be considered to have used loudness as a parameter for their productions.

Hixon, Minifie and Tait (1967) had two (non-naive) speakers produce /s/ and /ʃ/ at various self-determined levels of loudness and then assign a numerical estimate to each production based on a "median-range loudness" value of 100. The speaker-estimated loudness vs SPL slopes for these productions were reported as 0.63, in close agreement with Stevens' (1955) data. The authors interpreted their findings as supportive of Warren's (1962) contention that loudness rather than effort was the parameter used in AL judgements.

Two studies are worthy of note in light of the equation of loudness and/or intensity to effort as noted above. Pickett (1956) and Fairbanks and Miron (1957) reported studies dealing with "vocal force" (Pickett) or "vocal effort" (Fairbanks and Miron). While both studies purport to be dealing with effort *per se*, Ss in the two studies generated experimenter-determined, instrumentally-verified levels of vocal *intensity* which were assumed (perhaps rightly) to represent either eight (Pickett) or two (Fairbanks and Miron) levels of vocal effort. While the findings of both studies (related to intelligibility of speech) may indeed be relevant to the effort concept, it requires an act of great faith to assume that "low" or "very low" effort from one S can be equated with the same level from another S *in terms of vocal effort* when both Ss were forced to an external physical standard.

Clark *et al.* (1948), in a study of altitude effects on speech, were faced with the need for some "normal voice level" over a range of altitudes from sea level to 35,000 feet. After preliminary testing they decided to use a measured (in SPL) "maximum effort" as the standard for all levels and defined "maximum effort" operationally as the level 6 dB less than a physiological maximum (which could not be maintained without fatigue on S's part). Their preliminary tests required S-generated (1) true maximum effort levels and half-effort levels, followed by (2) half- and quarter-effort levels and (3) quarter- and eighth-effort levels (i.e., successive halvings), all of which were measured in SPL. All ALs were generated with S receiving "intense masking noise" via earphones. Ss showed reasonable constancy in their ALs and their half-effort dB reductions (4.5, 6.2 and 7.3 dB) composite slope of 1.0 was cited by Lane, Catania and Stevens (1961) as agreeing well with their AL findings which predicted a 5.5 dB reduction for halving.

Lane, Catania and Stevens (1961) obtained magnitude productions similar to those detailed above with S under conditions of (1) 110 dB masking noise, (2) wearing disconnected earphones and (3) wearing earphones with varying voice feedback and found the AL slope to be generally constant and consistent with the earlier-reported exponent.

Moll and Peterson (1969) had a speaker produce samples of /æ/ at fundamental frequencies (f_os) of 125, 175, 250 and 350 Hz. The speaker first recorded a sample at each f_o at a "comfortable" effort level. Subsequently each f_o sample was played back to the speaker from a tape loop while he generated other productions at that f_o at magnitude production intervals of 2 above and below the "comfortable" level value of 10. Analysis of the samples was performed to determine SPLs and the speaker's estimates vs SPL yielded slopes of 0.84, 0.65, 0.62 and 0.80, respectively, for the four f_os. The overall slope with f_os combined was 0.68.

Some of these same studies, and others, have dealt with effort and/or loudness from the viewpoint of the observer's (listener's) percept. They are presented below.

The equal-VU samples collected by Lehiste and Peterson (1959) were presented to listeners in random pairings with equal-effort samples for loudness ratings. The authors reported that "almost invariably, the listeners identified the vowels that were produced with a greater amount of effort . . . as louder than vowels having greater intrinsic amplitude, but produced with normal effort."

Lane, Catania and Stevens (1961) reported an additional experiment in which constant effort samples and live vocal productions over a 30 dB range yielded equally a listener-judged loudness slope of 0.7. Their conclusion was that AL ("the 'sound of effort'") had a negligible import in listener loudness judgements. The authors concluded by stating that "effort plays a major role in a speaker's judgement of his own vocal loudness, but that vocal loudness plays only a minor role in his judgement of autophonic output."

Lane (1962) reported a series of studies in which, among other conditions, AL and SPL were varied electronically singly as well as together, where listeners were to make loudness judgements. He found loudness exponents related to SPL rather than to AL in each instance, with slopes from 0.10-0.50, most, however, 0.40. Another series of studies as part of the same experiment utilized four /a/ productions at 10 dB intervals, at four f_0 levels. These samples were electronically processed for presentation of (1) f_0 only, (2) formant one only, (3) formants one and two only or (4) the total vowel. Listener loudness estimates of all presentations generated approximately the same function slopes (0.4). Lane's analysis of variance showed a second-order interaction between AL and SPL which he interpreted as evidence of an AL effect on loudness "at extreme values," but only for the total vowel and not attenuating the effects of SPL on loudness. Lane concluded that "the present study deals a coup de grace to the contention that vowel loudness is perceived in terms of vocal effort . . . ."

[This notion of perception according to production is not a new one and still maintains a certain currency. As early as 1932, Jones suggested "that the listener refers what he hears to how he would say it." Joos (1948) proposed that the initial acoustic production of a stranger is sampled, the various vowels typifying vowel triangle extremes compared to the listener's articulatory pattern and the subsequent acoustic input translated into the listener's dialect pattern.

Liberman (1957) formalized the concept as a motor theory of speech perception. Lehiste and Peterson (1959) suggested that stress may be perceived in terms of vocal effort. See Lane (1965) for an interesting review of the motor theory, pro and con.]

Ladefoged and McKinney (1963) utilized word samples generated at various loudness levels by a single speaker in an SPL vs subglottal air pressure investigation. Data from this study led them to formulate that work was proportional to the 1.2 power of SPL. These same word samples were presented to listeners in a sentential ("Compare the words: bar and ______") paired context for loudness judgements. The loudness judgements for those (midrange) samples with subglottal pressures between 10-30 gm aq were found to correspond to SPL measures with a slope of 1.2. The author's finding that both listener loudness estimates and subglottal pressures related to SPL with a 1.2 slope led them to suggest that listeners were in fact assessing the amount of work, i.e., the degree of effort, in forming loudness estimates. While this slope value was concurrent with Lane, Catania and Stevens' (1961) AL value, it was extremely divergent from their listener-estimate finding of a 0.7 slope and Lane's (1962) finding of a 0.4 slope.

Warren, Sersen and Pores (1958) proposed a _physical-correlate_ theory which held that loudness was perceived in terms of S's experiential knowledge of the effects of distance from the sound, hence that half-loudness and twice-distance judgements would be virtually identical. Their study to establish this with both a pure tone and recorded conversation presented to Ss for estimation yielded statistically equal values for the two judgement modes. The half-loudness slope for the tone was 0.94 and the twice-distance slope, 1.07. For the voice samples the judgements were virtually equal and the obtained half-loudness slope of 0.75 approximates the Lane, Catania and Stevens (1961) finding of a 0.7 slope for listener judgements. Warren, Sersen and Pores referred to Pollack (1952) who also found greater dB changes necessary for half-loudness or twice-distance judgements for speech stimuli than for tone stimuli. Pollack's findings, however, were not comparable to those of Warren, Sersen and Pores in that Pollack's data yielded a slope of 0.4.

The above data of Warren, Sersen and Pores (1958) were repeated in Warren (1963), together with a synopsis of Warren (1962) toward countering the proposal by Lane, Catania and Stevens (1961) that ALs were judged by any criterion but loudness. Warren (1963) did add the comment that the physical-correlate theory requiring distance as the parameter of judgement obviously could not pertain when S was himself the source and S could rely only on intensity as a judgement basis.

The stimuli generated by Moll and Peterson's (1969) speaker were presented to listeners for judgement against a paired standard, with one listener group instructed to judge loudness and a second to judge "degree of effort." The two estimates were found to be essentially identical and were combined. Slopes reported for the listener ratings for the four f_os (low to high respectively) were 0.50, 0.55, 0.70 and 0.72, with a combined-f_o slope of 0.61. In this study--the first to specifically investigate the correspondence--loudness and vocal effort were perceived identically. All judgements were made within an f_o level and no comparison could be made between levels except to note that listener judgement slopes were progressively greater as f_o increased. Lane (1962) also utilized several f_o levels but AL and f_o covaried and f_o was not studied.

Hixon, Minifie and Tait (1967) had judges make magnitude estimation loudness ratings of Ss' AL productions and the authors reported substantial agreement between the judges and the individual Ss, concluding that S operated as a self-monitor in the same fashion that the judges operated as other-monitors: judging on the basis of loudness alone.

Mendel et al. (1969) presented several stimuli groups to listeners for loudness judgements, including instrument-produced sounds (tones, white noise), speech at a single AL (electronically-varied for presentation level) and autophonically-varied speech (isolates, monosyllables, monosyllabic words and connected speech). Listeners' judgement data produced loudness exponent levels from 0.80-0.86 for machine-generated signals, 0.74-0.84 for electronically-varied speech and 0.86-1.20 for autophonically-varied speech. These AL data are counter to those of Lane (1962) but agree well with Ladefoged and McKinney's (1963) data.

Brandt, Ruder and Shipp (1969) utilized sentential speech samples (repetitions of one emotionally-neutral sentence) generated by one S at eight SPLs from 60-95 dB. Listeners were presented (1) samples at the originally-recorded levels, i.e., AL, SPL and f_0 covaried, (2) samples of varied AL with SPL electronically held constant and (3) samples with AL held constant and SPL electronically varied. Listeners were instructed to judge the samples for loudness and, after a rest period, for "perceived amount of effort used by the speaker" against a standard stimulus which was presented first during each experimental condition. Slope values were reported as follows: for normal speech, loudness (L) 1.12 and effort (E) 0.89; for constant SPL and varied E, L 0.40 and E 0.57 and for varied SPL and constant E, L 0.92 and E 0.38. When effort was held constant, both loudness and effort judgements were reduced although effort did not fall to zero as it theoretically should have. The authors suggested a pervading loudness effect influencing effort judgements. Together, these data suggest that listeners indeed perceive loudness and effort separately. Since increased intensity yields an increased signal bandwidth, the authors suggested bandwidth as the physical basis for their data.

Allen (1971) essentially replicated the Ladefoged and McKinney (1963) study, analyzing the centrally-located 30 (of 60) word samples. He utilized a partial correlation analysis of loudness with SPL and subglottal pressure and reported both parameters as being important with individual Ss seeming to rely more heavily on one than the other. In a second experiment, Allen used words uttered at 13 "subjectively constant effort" levels as stimuli in the sentential frame: "Ready? How loud is this word? ______." The stimuli were presented to listeners under each of three attenuations and each of three masking conditions (9 conditions total) in an attempt to separate SPL and vocal effort effects. The data were again inconclusive, varying from S to S, leading Allen to state that "subjects appear to use both intensity and effort cues in a way that is not obviously manipulable."

Brandt (1972a) replicated the Brandt, Ruder and Shipp (1969) study with the added condition of all stimuli being bandpass filtered (200-2000 Hz). The non-filter data were reported as essentially the same as the original experiment except that the slope magnitudes were reduced. The constant SPL condition slope decreased to 0.22 (from 0.40) and the constant effort condition slope reduced to 0.07 (from 0.38), more in line with expectation. The slope values developed under the filter condition were reduced from the non-filter slopes for loudness but the effort slopes remained essentially the same (slightly rising in two conditions) and Brandt concluded that bandwidth "is not important in the perception of vocal effort." Analysis of the original samples showed f_o to rise with increases in SPL, and Brandt suggested that for the listener the "combination of f_o (pitch) and intensity (loudness) is the cue for judging vocal effort."

Brandt (1972b) selected three production levels and three f_o levels from the stimuli of the Brandt, Ruder and Shipp (1969) study and processed these samples to generate (1) normal speech, (2) equal effort, varied intensity and (3) varied effort, equal intensity conditions. Listeners were assigned the task of matching a dc pulse train "periodicity pitch" to the f_o of the sample sentences. He reported that Ss did indeed match pitch to f_o levels and that intensity changes little interfered with these judgements. Brandt suggested " that vocal effort is indeed different from vocal loudness and what listeners perceive as vocal effort are really the long term acoustic correlates of laryngeal function."

Prebor (1970) studied voice qualities as a function of interpersonal distance and found that pitch, loudness and effort increased with increased distance, based on naive-listener comparison ratings of conversations recorded at varying distances. He also reported a significant correlation ($p < .001$) between loudness and effort. It cannot be determined whether his Ss differentiated between loudness and effort in making their judgements although the correlation noted suggests not. Effort, as Prebor points out, "although undefined acoustically" has "promise as a meaningful feature of voice quality," and its underlying physical parameter(s) must be experimentally determined.

Purpose

The two parameters of voice pervading the effort studies are intensity and f_0. To date no study has systematically examined both fully although Brandt, Ruder and Shipp (1969) and Brandt (1972a; 1972b), taken together, approximate this goal. In fact, although f_0 has been controlled in various studies, it has been utilized as an experimental variable in only the Moll and Peterson (1969) study.

The present study, then, was an attempt to systematically examine the effect of both intensity and f_0 on listener judgements of vocal effort. In the current study, a set of 40 sustained vowel samples recorded by one male speaker were utilized as experimental stimuli. These samples represented an eight-intensity-level by five-f_0-level matrix of the vowel /ɛ/. In addition to production control of both factors, laboratory manipulation was performed to equalize (1) f_0, (2) intensity and (3) both f_0 and intensity. A fourth manipulation utilized a single production sample from which artificial samples representing all f_0 and intensity levels were created.

These stimuli were presented to listeners for their magnitude estimates of the (1) vocal effort, (2) loudness and (3) pitch perceived in each sample. These judgements were subsequently analyzed in order to determine (1) whether the percept of vocal effort was indeed different from percepts of loudness and pitch and (2) what contribution (a) f_0 and/or (b) intensity made to these percepts.

II

PROCEDURE

The present study was designed to investigate the frequently-described and often-used concept of vocal effort in an attempt to relate the percept of vocal effort to the physical voice parameters of intensity and/or fundamental frequency (f_o).

Subject

One adult male (the experimenter) was used as the speaker for this study. S evidenced no abnormalities of speech or hearing and was a native speaker of American English. S met the criterion of being able to perform the experimental task.

Production Samples

The S produced sustained phonations of the vowel /ɛ/ at 60-95 dB SPL in 5 dB increments at f_os of 123, 138, 155, 174 and 196 Hz (i.e., one-tone steps from 17.5-21.5 tones re 16.35 Hz), yielding a total of 40 samples. Table 1 lists these 40 production samples in matrix form. The intensities selected approximately cover S's complete range of production capability and the f_os were felt to provide a reasonable sample of S's frequency range. The vowel /ɛ/ was selected anticipating future high-speed photographic study of the vocal folds should it appear that there are physical correlates attributable to the folds in the effort percept.

Table 1. Production Stimuli

Frequency (Hz)		Intensity (dB SPL @ 4")							
	123	60	65	70	75	80	85	90	95
	138	60	65	70	75	80	85	90	95
	155	60	65	70	75	80	85	90	95
	174	60	65	70	75	80	85	90	95
	196	60	65	70	75	80	85	90	95

Recording Procedure

S was seated in a sound treated room (IAC 1204A). S was positioned such that his lips were a constant four inches from the recording microphone, and all SPLs cited relate to this distance. (A rule was taped to the microphone and S positioned himself before each production so that his upper lip just contacted the rule.) S received a sine wave from a (Beckman 9010) function generator through an amplifier (Magnecord) monaurally via a (TDH-39) earphone as the criterion level for each f_o production. S was instructed to vary his f_o appropriately to produce beats (of imperfect unison) toward matching the criterion frequency. The function generator was set by the experimenter to the required frequency according to measurement by a (Monsanto 101B) frequency counter. The experimenter monitored S's production as well as the frequency standard, also using beats as an acceptability criterion.

A (General Radio 1551-A) sound level meter, set to the 20 kc scale, was used to determine SPL. The meter was positioned immediately in front of S at an appropriate height and the meter microphone was used as the recording microphone, the meter output being patched into a tape recorder (Sony TC630) which was located outside the experimental room. An appropriate recording level was determined for the tape recorder and maintained as a constant over all samples. S was instructed to maintain an intensity level of either 0 or +5 dB on the sound level meter according to the required sample and the experimenter introduced 0 or 5 dB attenuation respectively (Hewlett-Packard 350D passive attenuator and a buffer) so that the input to the recorder was constant at approximately 0 dB VU. The sound level meter range switch was adjusted and 10 dB attenuation steps were introduced as the production SPL increased.

The effect of these attenuations, as of those noted above, was to maintain a constant level to the recorder, placing all samples in the optimum range of the recorder and insuring high quality reproduction.

S attempted a particular production and when the experimenter determined that the vowel, the f_o and the intensity met the condition requirements, a three to five second sample was tape recorded, and the next condition begun. If either S or an experimental assistant objected to a particular sample on any basis it was immediately redone. As an f_o-intensity level was completed, the experimenter adjusted the function generator and/or the sound level meter for the next condition.

Since the experimenter was present in the experimental room to observe and approve the generated productions as well as to operate the control equipment, it was necessary to have an assistant outside the room to actuate the tape recorder when sample production was verified and recording desired. The experimenter signaled the assistant via a foot-actuated signal light which could be operated without noise or obvious motion.

S vocally identified each sample as to f_o and SPL on the tape recording prior to production.

At an initial recording session S produced one accepted sample of each f_o-intensity level. The eight intensities were produced, low to high, at the lowest f_o, the next higher f_o, . . ., the highest f_o (i.e., F1, I1-8; F2, I1-8; F3, I1-8; F4, I1-8; F5, I1-8).

When it was noted that several samples from the above group failed to meet the intensity level criterion in subsequent level recorder analysis (described below), a second recording session was scheduled. Since in the first session it was found that production of the higher intensity levels induced fatigue or strain such that S had difficulty in producing the required low intensity level for the next f_o, the order of recording was changed. In the second session all f_os were produced at the lowest intensity level, the next intensity level, etc., through the highest level (i.e., I1, F1-5; I2, F1-5; . . .; I8, F1-5).

To provide a measure of certainty that a valid sample would be available at each level, several seemingly-acceptable samples were produced and recorded for each f_o-intensity level. Samples were thus available from the two recording sessions, each session covering the entire production matrix (40 items), providing multiple attempts at each level from which a single valid instance could be selected.

A schematic of the recording equipment is provided as Figure 1.

Sample Validation

The original tape recording was played into a (Brüel and Kjaer Type 2305) level recorder. From the available samples at a particular f_o-intensity level a sample was selected which met the criterion of ± 2 dB relative to the mean level of all selected samples and ± 1 dB over the duration of the individual sample.

Those samples selected according to the intensity criteria noted above were then subjected to a frequency validation procedure. An electronically-switched excerpt of duration equal to the intended presentation duration (1300 msec) was obtained from each of the 40 samples and played into an oscillograph (Honeywell 1508A Visicorder). The obtained tracings were analyzed and a sample was discarded if it exceeded a ± 3.5 Hz deviation from the prescribed f_o level. For those instances where a sample was discarded (five) another sample was selected from those found acceptable according to the intensity analysis above, an excerpt

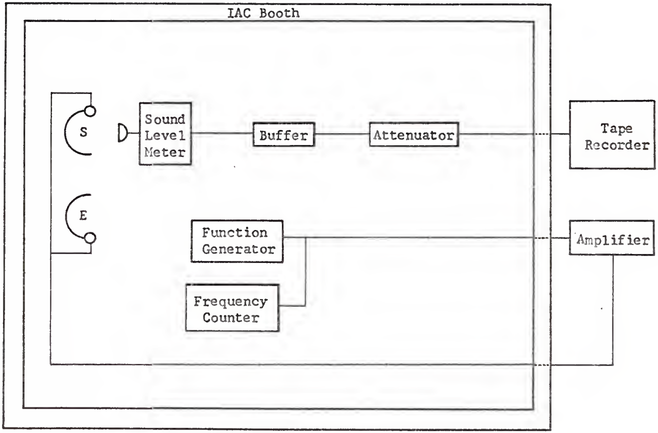


Figure 1. Recording Equipment

obtained, and the frequency analysis repeated.

All samples utilized in the experiment, then, were at the prescribed intensity ± 2 dB and f_o ± 3.5 Hz. After this physical validation of the samples, it was deemed legitimate to introduce such electronic intensity adjustment as necessary in the dubbing procedures to maintain the actual intensity relationships of production.

Stimuli Preparation

The production samples were recorded on channel one of the two channel tape recorder. The experimenter played the tape recording, monitoring the productions and, immediately at onset of a sample group, actuated a pulse generator to place an electronic pulse on channel two of the tape. The final preparation phase utilized this pulse to actuate an electronic switch gating circuit to extract a sample 1300 msec long with rise and decay times of 35 msec (perceptually determined as presenting no onset or offset artifacts). Sample extraction in this manner served a dual purpose: (1) it eliminated any production onset or offset phenomenon which might provide a perceptual cue not under experimental control or examination and (2) assured physical identicality of stimuli as regards duration, onset and offset.

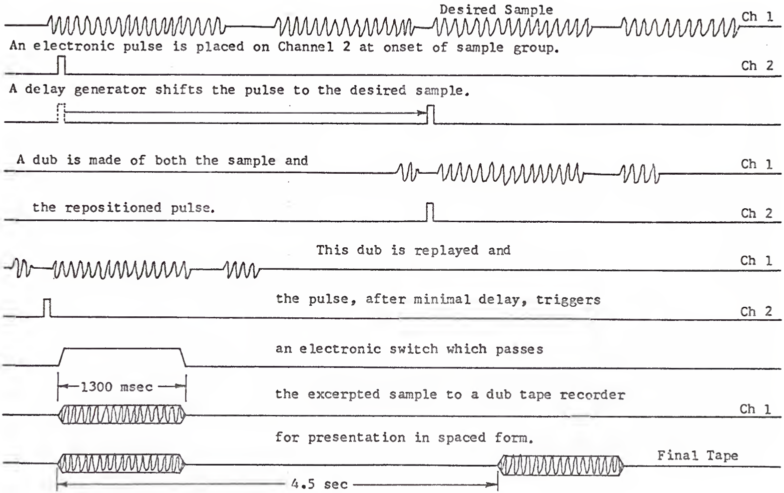
As noted above, identification of a valid sample was accomplished via physical validation procedures. The physical implementation of sample selection utilized the pulse on channel two of the tape recording in the following manner. The original production and the pulse were both displayed on the level recorder. The pulse was passed through a delay circuit such that it could be positioned so as to immediately precede the desired sample. This adjustment was made individually for each sample. When the correct adjustment was obtained both the vocal identification made by S and the sample were dubbed onto another tape recorder (Sony TC530) on channel one and the pulse was dubbed onto channel two in its relocated position relative to the required sample. Figure 2 illustrates the sample extraction paradigm.

These validated samples and their associated triggering pulses were then manipulated as necessary to provide the experimental stimuli as described below.

One set of stimuli existed as a result of the recording procedure: samples with intensity constant and f_o varied over five levels. The remainder of the stimuli sets had to be electronically or mechanically generated.

Since all samples, as recorded, were at the same relative intensity level, returning them to what was the production situation involved merely introducing the same attenuations already introduced in the recording procedure, but in reverse order. In other words, the experimenter had to attenuate the 95 dB samples 0 dB, the 90 dB samples 5 dB, . . ., and the 60 dB samples 35 dB in a dubbing step. This provided a replicate of the "live" situation with real f_o and real intensity, both experimentally varied.

A third stimuli set required mechanical adjustment of f_o to bring all samples to the center f_o level (155 Hz). To accomplish this, a variable-frequency power supply (Harrington, 1973) was used to adjust the speed of the synchronous drive motor in a (Sony 350D) tape deck. A sine wave at the frequency of an f_o (say, 123 Hz) was recorded on tape at normal speed (i.e., using line power at 60 Hz). The variable-frequency power supply was substituted for line power and the power



An electronic pulse is placed on Channel 2 at onset of sample group.

A delay generator shifts the pulse to the desired sample.

A dub is made of both the sample and

the repositioned pulse.

This dub is replayed and

the pulse, after minimal delay, triggers

an electronic switch which passes

the excerpted sample to a dub tape recorder

for presentation in spaced form.

Figure 2. Stimulus Preparation

frequency raised to increase (in this instance) the speed of the tape deck until the recorded frequency yielded a frequency counter reading of 155 Hz. The master recording was then placed on the tape deck and those samples at the particular (in this example, 123 Hz) f_o level were dubbed onto another tape recorder (Sony TC630). Each f_o level (except, of course, the 155 Hz level) was dubbed in this fashion to equalize f_o levels. These dubbings provided an equal f_o, equal intensity set of stimuli.

It remained only to replicate the procedure used for the second stimuli set (dubbing at reversed attenuation levels) to generate from the third set a fourth stimuli set: stimuli with equal f_o and varied intensity.

Preparation of the fifth stimulus set necessitated making a dub of the 155 Hz, 80 dB SPL production, with the frequency raised or lowered in a procedure similar to the frequency manipulation description above, to simulate the other four f_o levels. These created samples (155 Hz plus four artificial f_os) were then dubbed with appropriate attenuation levels introduced to create eight intensity levels at each f_o. A matrix of one real and 39 artificial stimuli was thus provided wherein the production effort was equal across samples since all were derived from a single production level.

These frequency-manipulated stimuli, along with the unmanipulated original stimuli, were played into the level recorder through an electronic switch, with the channel two pulse used to gate the switch. Intensities were measured for each excerpt and notation made of the attenuation required to generate the individual presentation levels. The final stage of preparation required inserting the necessary attenuation (individual for each final sample) prior to final dubbing. Utilizing a prepared chart whereon samples were ordered according to a random selection procedure from the five manipulation sets, the final stage was accomplished.

After locating the required sample the experimenter made the appropriate line connections such that the channel two pulse (1) gated an electronic switch and (2) actuated the solenoid of the SOIS (Signal Onset Interval System) tape recorder (Sony TC530), providing both stimulus excerpt and interstimulus interval. The final tape contained dubs of the experimenter's recording of the word "standard" followed by presentation of the 155 Hz, 80 dB stimulus which was used as the reference level.

Table 2 is a matrix of the experimental stimuli showing the produced and presented f_0 as well as the produced and presented intensity. For purposes of analysis these samples were reordered into five blocks of 40 stimuli according to the manipulation(s) performed. Consequently there were the following stimuli blocks: real frequency and real intensity (RR); real frequency and manipulated intensity (RM); manipulated frequency and real intensity (MR); manipulated frequency and manipulated intensity (MM); and artificial frequency and artificial intensity (AA).

Presentation Tapes

The final dubbing of the stimuli provided a tape recording containing the word "standard," the 155 Hz, 80 dB reference level and 25 stimuli for judging, followed by six additional sets of word, reference and 25 stimuli. There were in all, then, 175 stimuli plus seven presentations of the reference level. Although there are 200 stimuli

Table 2. The Experimental Stimuli

		Intensity Produced/Presented							
Frequency Produced/Presented	123/123	60	65	70	75	80	85	90	95
	123/123	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	123/155	60	65	70	75	80	85	90	95
	123/155	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	155/123	80/60	80/65	80/70	80/75	80/80	80/85	80/90	80/95
	138/138	60	65	70	75	80	85	90	95
	138/138	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	138/155	60	65	70	75	80	85	90	95
	138/155	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	155/138	80/60	80/65	80/70	80/75	80/80	80/85	80/90	80/95
	155/155	60	65	70	75	80	85	90	95
	155/155	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	155/155								
	155/155								
	155/155	80/60	80/65	80/70	80/75	"	80/85	80/90	80/95
	174/174	60	65	70	75	80	85	90	95
	174/174	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	174/155	60	65	70	75	80	85	90	95
	174/155	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	155/174	80/60	80/65	80/70	80/75	80/80	80/85	80/90	80/95
	196/196	60	65	70	75	80	85	90	95
	196/196	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	196/155	60	65	70	75	80	85	90	95
	196/155	60/80	65/80	70/80	75/80	"	85/80	90/80	95/80
	155/196	80/60	80/65	80/70	80/75	80/80	80/85	80/90	80/95

Note: Production Intensity in dB SPL; Presentation Intensity in dB SL
Frequency in Hz

represented, inspection of Table 2 will show that 26 stimuli were duplicated (e.g., while 123 Hz had to be manipulated to 155 Hz, 155 Hz was itself, and while 60 dB had to be manipulated to an 80 dB presentation level, 80 dB was already 80 dB). The duplicated stimuli were presented only once and the 175th stimulus, introduced to maintain the 25-stimuli grouping, was a duplicate of the first stimulus and was discarded before data reduction. Duplicate entries were made in the data reduction for duplicated stimuli prior to analysis.

From this final tape recording three duplicate dubbings were made onto a single track tape recorder (Ampex 351). These three tapes were presented sequentially to listeners during each experimental session.

Practice Tapes

One additional dubbing was made of the first 25 stimuli plus the first five stimuli from the second group. The practice tape consisted, therefore, of the word "standard," the 155 Hz, 80 dB reference, 25 stimuli, the word "standard," the 155 Hz, 80 dB reference and five stimuli. Additionally, a 500 Hz square wave at 80 dB SPL was recorded at the beginning of the practice tape to serve as a calibration tone. The practice tape was used both to provide task practice and as an aid in qualifying prospective listeners.

Listeners

Listeners were young adult male students (N = 24) at the University of Florida, Gainesville, who spoke American English and could be presumed to be experientially familiar with vocal qualities commonly occurring in American English. Listeners had no experience of a magnitude estimation task prior to the experiment. The listener group was limited to males to avoid any possible cross-sexual influence. Prospective listeners were sought via classified advertisements in the student newspaper and by posted notices. Listeners selected for the experiment were paid a nominal fee for their time. All prospective listeners were subjected to a qualifying interview as described below.

Listener Qualification

Each prospective listener was administered an audiometric test and rejected if his hearing loss at any screened frequency (250, 500, 1000, 2000 and 4000 Hz) exceeded 10 dB (ISO 1964) in his better ear. Approximately one-third of the applicants were rejected on this basis.

When an applicant passed the hearing test he was given written instructions describing his task (Appendix A) which he read while the experimenter readied the practice tape, setting the presentation level according to the applicant's particular hearing level as described below under Presentation.

When the applicant completed the instructions the experimenter had him briefly explain the task. When it was clear that the applicant understood his task the experimenter administered the practice tape and checked the responses. The experimenter first verified that the applicant responded to each practice stimulus--two applicants were rejected when it was found that they had not heard one or two stimuli and could not hear them on a repeat presentation of the practice tape--and that he appeared to be performing the task correctly. The applicant was then questioned as to his willingness to perform the complete experiment and, if willing, was scheduled for a convenient time for his first experimental session (of three). If possible, all three sessions were scheduled at this time, otherwise at the first the second was scheduled and at the second, the third scheduled. At this time, also, an informed consent form was obtained from the listener.

Task

Listeners were instructed to attend to either (1) effort, (2) loudness or (3) pitch during each of three experimental sessions. Since it was felt that the order of task presentation might influence listener judgements, the three tasks, judgement of effort (E), loudness (L) and pitch (P), listeners were grouped for task order presentation of (1) ELP, (2) EPL, (3) LPE, (4) LEP, (5) PEL and (6) PLE. Applicants who qualified for the experiment were assigned sequentially to these orderings and performed the first task at the qualifying interview with the practice tape. In a particular session a listener attended to only a single task and the other tasks were not mentioned to him except that the experimenter did inform each listener at the conclusion of a session that his "task would be different" for the next session.

To avoid possible fatigue effects listeners were permitted to perform only one task on a given day, requiring, therefore, three separate days, consecutive where possible. In practice the spacing ranged from consecutive days to a three week span for individual listeners.

The actual task, regardless of the judgement parameter, was to assign some value deemed appropriate (by the listener) to the reference level and to then make magnitude estimates of the other stimuli in ratio to this reference level. Listeners were thus free to select a range of numbers with which it was "comfortable" for them to work (see Wright, 1965).

Since the reference level (155 Hz, 80 dB) appeared within the randomization of stimuli, listeners made a judgement of the "standard" although it was not then identified as being the "standard."

No listener was advised of the purpose of the study until completing his third task.

Presentation

It was noted above that each listener was audiometrically tested. The threshold values derived from these tests were used as the basis for the presentation levels, with all stimuli given in dB SL, specifically for the individual listener, based on and presented monaurally to the better ear (Hellman and Zwislocki, 1961; 1963). Presentation levels were calculated as 6.5 dB SPL (ISO 1964 @ 1000 Hz) plus 95 dB (maximum stimulus level) plus 0, 5 or 10 dB (hearing loss) minus 124.5 dB SPL, yielding -23, -18 or -13 dB re the 124.5 dB SPL (based on earphone calibration 1000 Hz value as given in Table 3).

Presentation was made to a single listener at a time. The listener was seated comfortably in front of a table in a sound treated room (IAC 1204A). The written instructions for the task (Appendix A) were brought to the listener's attention and the experimenter had the listener review the task aloud. A repeat of the practice tape was offered each listener but no listener felt it was necessary. At succeeding sessions the written instructions for the new task were provided the listener.

Taped to the wall in front of the listener was a 5 X 7 inch white card with the word "RATIO" appearing in block capitals. A second similar card was taped below the first, the second card having the word "EFFORT," "LOUDNESS," or "PITCH" according to the task.

Table 3. TDH-49 Earphone Calibration Values

Test Frequency	SPL
63 Hz	124.6 dB
125	121.8
250	123.8
500	124.0
1000	124.5
2000	123.6
4000	123.7
8000	111.3

In preparation for a particular listener the experimenter calibrated the equipment to the proper presentation level and verified that the task card on the wall was the correct one. The listener's better ear was to be used and the single (TDH-49) earphone was thus placed to that side of the table.

Stimuli were presented from a single track tape recorder (Ampex 351). The listener was provided with one mimeographed response sheet (Appendix B) at a time, each sheet covering one presentation tape of 175 stimuli. The listener was provided with a ball point pen (Bic, medium point, blue) to discourage any tendency to change a response as might occur were a pencil allowed. (Some listeners overcame this discouragement and crossed-out or wrote over those answers they wished to change.)

Provision was made for a break between the tapes but no listener requested time beyond that necessary for tape change. The completed response sheet was returned to the experimenter before the succeeding sheet was provided.

Subsequent data examination indicated that one listener had omitted a low-intensity (60 dB) stimulus on eight of the nine presentations (three presentations for each of three tasks) and data from this listener were discarded. Another listener provided magnitude estimates on the effort task of up to 80 (with a base level of 1) and it was felt that since his performance was not comparable to the other listeners his data too should be discarded. Unfortunately both these listeners were in the same order group, reducing the listeners in this group to two. In order to maintain a balanced design, two listeners were eliminated from each of the other five groups, reducing the total listener group to

N = 12. Listener elimination was based on consistency rather than on a random selection basis since it was noted that some listeners tended to an extreme inconsistency in their judgements from repetition to repetition. The 12 listeners utilized in the analysis were therefore the most consistent of the original listener group.

One further modification was required due to experimenter error. Examination of the listener judgements showed an extremely high value for the 174 Hz, 60 dB sample in the RR block on both the effort and loudness tasks. Subsequent reexamination of the presentation tape proved that the stimulus had been erroneously dubbed and presented at approximately 80 dB rather than the intended 60 dB level. A synthesized value was substituted for the listener-generated value for this stimulus (based on the trend evident for each listener and appropriate to the other 60 dB judgements) for both effort and loudness and these synthesized values were utilized in the data analysis.

Analysis

The three listener responses per task were totaled and a mean value derived. These mean values were then normalized to a reference base level of 100 for all listeners and a log transform computer-performed on these mean data. The data for each manipulation block (RR, RM, MR, MM and AA) were subjected to a computer analysis of variance under a split-plot factorial design (subjects, i.e., listeners, nested in order). The experimental design is illustrated in Figure 3. A posteriori paired comparisons using the Neumann-Keuls (Kirk, 1968) procedure were performed where indicated by significance in the analysis of variance of the RR block.

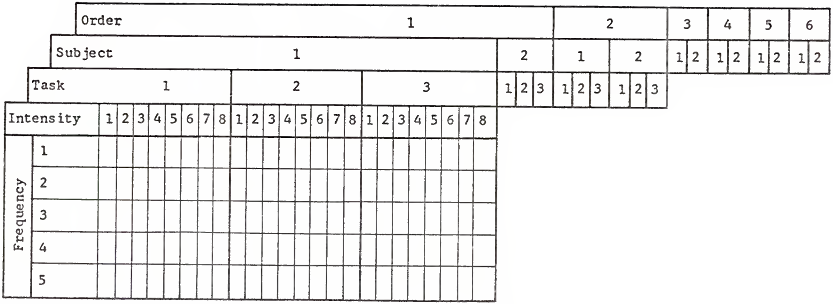


Figure 3. The Experimental Design

Mean data (cell means) from the analysis of variance were also prepared in graphic form. Slope calculations for the various factors were performed by a least squares method for comparison to previous experimental findings.

Results are reported below together with a discussion of the findings.

III

RESULTS AND DISCUSSION

In order to examine the effect of fundamental frequency (referred to herein as frequency and abbreviated as F) and intensity (I) of the human voice on listener's judgement of relative vocal effort, the present study required a speaker to produce the same vowel at each of five Fs at each of eight I levels. These productions were laboratory-manipulated to create four other groups of stimuli in addition to the actual productions: (1) real F and equal I; (2) equal F and real I; (3) equal F and equal I and (4) artificial F and artificial I. An electronic excerpt of controlled duration and shaping was taken from each sample in each group, and all excerpts were randomized and presented to 12 listeners for judgement of the (1) effort, (2) loudness and (3) pitch of each sample in ratio to a base or reference level. The 12 listeners were divided into six groups of two listeners, each group performing the three judgement tasks (T) in a different ordering so that the effect of task order (O) could be examined. The listeners' judgement data, after a log transform to achieve numerical linearity, were subjected to analysis of variance under a Split Plot Factorial design.

The analysis of variance summary is given as Table 4. Examination of the calculated _F_ ratios showed significant values to exist at the 5% level of significance for three main effects (order, frequency and intensity), for four two-way interactions (task/frequency,

Table 4. Analysis of Variance Summary Table

Source	Error Term	SS	df	MS	F
T(Task)	TS(0)	0.3491	2	0.1971	1.5399
0(Order)	S(0)	7.7546	5	1.5509	5.7083*
F(Frequency)	SF(0)	4.5614	4	1.1404	35.6828*
I(Intensity)	SI(0)	95.4469	7	13.6353	80.0247*
S(0)(Subjects)		1.6302	6	0.2717	
TO	TS(0)	2.6121	10	0.2612	2.0411
TF	TSF(0)	4.7326	8	0.5916	23.4301*
OF	SF(0)	1.9625	20	0.0913	3.0705*
TI	TSI(0)	19.1146	14	1.3653	31.5188*
OI	SI(0)	1.8297	35	0.0523	0.3068
FI	SFI(0)	2.8771	28	0.1028	11.0176*
TS(0)		1.5357	12	0.1280	
SF(0)		0.7700	24	0.0320	
SI(0)		7.1563	42	0.1704	
TOF	TSF(0)	1.3985	40	0.0350	1.3848
TOI	TSI(0)	7.1366	70	0.1020	2.3536*
TFI	TSFI(0)	1.0145	56	0.0181	2.0887*
OFI	SFI(0)	1.7953	140	0.0128	1.3750*
TSF(0)		1.2119	48	0.0252	
TSI(0)		3.6387	84	0.0433	
SFI(0)		1.5668	168	0.0093	
TOFI	TSFI(0)	2.8023	280	0.0100	1.1539
TSFI(0)		2.9143	336	0.0088	

*Significant at 5% level of significance

order/frequency, task/intensity and frequency/intensity) and for three three-way interactions (task/order/intensity, task/frequency/intensity and order/frequency/intensity). These significant effects may be found marked by an asterisk in Table 4. Where significant _F_ ratios were noted, paired comparison _a posteriori_ tests were performed using the Neumann-Keuls procedure (Kirk, 1968) in all instances.

Where higher order interactions are statistically significant, the information to be derived from these interactions must be considered in interpretation of any lower order interaction and, ultimately, in interpretation of main effects. Since interpretation begins with the high order interactions, results are presented in tabular form for the three-way interactions, the two-way and then for the main effects. Discussion of the results, however, is presented under headings pertinent to the research questions, and a particular interaction is viewed at that time only for that portion relevant to the factor (task, order, intensity or frequency) under consideration.

The results which follow are extensive and complex. So as to be able to retain some grasp of the implications of a given interaction by keeping tables on a single page wherever possible, the writer has made extensive use of the abbreviations T, O, F and I (combined with numerals) rather than writing out task, order, frequency and intensity. Table 5 provides a letter-number coding key as an aid to the reader.

A Posteriori Comparisons

The Neumann-Keuls procedure (Kirk, 1968) requires ordering of means from low to high value before comparisons are made. While such ordering can be done by inspection where there are relatively few means,

Table 5. Key to Factor Coding

Factor	Code	Meaning
Task	T1	Judgement of Effort
	T2	Judgement of Loudness
	T3	Judgement of Pitch
Order	01	Effort, Loudness, Pitch
	02	Effort, Pitch, Loudness
	03	Loudness, Pitch, Effort
	04	Loudness, Effort, Pitch
	05	Pitch, Effort, Loudness
	06	Pitch, Loudness, Effort
Frequency	F1	123 Hz
	F2	138 Hz
	F3	155 Hz
	F4	174 Hz
	F5	196 Hz
Intensity	I1	60 dB
	I2	65 dB
	I3	70 dB
	I4	75 dB
	I5	80 dB
	I6	85 dB
	I7	90 dB
	I8	95 dB

it would be virtually impossible for the reader to do so for the three-way interactions and difficult in several other instances. The writer, therefore, has prepared tables showing the interaction mean ordering. For a three-way interaction, for example, there are three tables, each showing the ordering of a given factor in terms of the other two. These tables, with the addition of data values in matrix form, were used for the actual a posteriori comparisons. Since data contained in the presented tables is by rank ordering only, the ordering tables alone are not a reliable guide to interpretation.

Three-way Interactions

Table 6 presents the mean log judgement values for the order/frequency/intensity interaction. Table 7 presents the ordering for the factor, order, followed by Table 8 which lists the significant comparisons involving order. It may be noted that order 3 (LPE) nearly always yielded the lowest mean values and significantly (5% level of significance) differed from the other orders in many instances. The ordering for frequency is given in Table 9 and Table 10 lists the significant frequency comparisons. It is interesting and surprising to note the number of instances in which frequency did not significantly differ. The ordering for intensity is provided in Table 11 and the significant comparisons for intensity appear in Table 12.

The mean log judgement values for the task/frequency/intensity interaction are presented in Table 13, followed by factor ordering for task in Table 14 with the significant (5% level of significance) task comparisons detailed in Table 15. Task 3 (P) is seen to be significantly larger than the other tasks at the lower intensities and significantly smaller at the higher intensities, the changeover occurring at

Table 6. Order/Frequency/Intensity Interaction--
Mean Log Judgement Values

Order 1

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.302	1.574	1.758	1.896	2.036	2.148	2.319	2.449
	2	1.487	1.762	1.834	1.956	2.025	2.320	2.215	2.476
F	3	1.584	1.772	1.741	2.052	2.075	2.209	2.313	2.522
	4	1.710	1.764	1.769	2.078	2.101	2.300	2.364	2.563
	5	1.791	1.813	1.963	2.006	2.173	2.177	2.458	2.561

Order 2

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.387	1.694	1.802	1.984	2.016	2.053	2.251	2.341
	2	1.579	1.782	1.842	1.913	2.008	2.143	2.180	2.306
F	3	1.577	1.717	1.748	1.955	2.027	2.123	2.202	2.296
	4	1.665	1.600	1.722	1.979	2.031	2.104	2.207	2.278
	5	1.657	1.789	1.792	1.941	2.062	2.169	2.220	2.351

Order 3

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.318	1.494	1.588	1.681	1.890	1.947	2.087	2.145
	2	1.385	1.598	1.621	1.720	2.037	2.037	2.000	2.156
F	3	1.420	1.592	1.559	1.837	1.806	2.075	2.016	2.215
	4	1.474	1.568	1.652	1.870	1.836	2.003	2.093	2.135
	5	1.522	1.597	1.651	1.813	1.855	2.155	2.111	2.173

Table 6. extended

Order 4

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.230	1.496	1.729	1.896	1.942	2.050	2.130	2.220
	2	1.437	1.792	1.770	1.896	1.972	2.050	2.027	2.260
F	3	1.500	1.708	1.714	1.971	1.977	2.060	2.090	2.231
	4	1.553	1.716	1.795	2.010	1.975	2.033	2.170	2.180
	5	1.601	1.744	1.890	2.006	2.010	2.082	2.190	2.249

Order 5

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.316	1.572	1.719	1.865	2.007	2.111	2.349	2.432
	2	1.495	1.736	1.797	1.869	1.979	2.263	2.158	2.481
F	3	1.550	1.677	1.713	1.921	2.053	2.161	2.278	2.470
	4	1.670	1.853	1.834	2.044	2.006	2.235	2.395	2.493
	5	1.735	1.853	1.950	2.035	2.136	2.208	2.397	2.498

Order 6

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.392	1.456	1.632	1.848	1.881	2.097	2.205	2.205
	2	1.437	1.655	1.818	1.876	2.021	2.171	2.171	2.325
F	3	1.584	1.656	1.686	1.925	1.982	2.228	2.217	2.324
	4	1.742	1.965	1.808	2.220	2.071	2.273	2.279	2.368
	5	1.940	2.036	2.062	2.158	2.225	2.288	2.404	2.441

Table 7. Intensity/Frequency/Order Factor Ordering, Low to High

		Order			Order			Order			Order
I1	F1	4 1 5 3 2 6	I2	F1	6 3 4 5 1 2	I3	F1	3 6 5 4 1 2	I4	F1	3 6 5 4 1 2
	F2	3 4 6 1 5 2		F2	3 6 5 1 2 4		F2	3 4 5 6 1 2		F2	3 5 6 4 2 1
	F3	3 4 5 2 6 1		F3	3 6 5 4 2 1		F3	3 6 5 4 1 2		F3	3 5 6 2 4 1
	F4	3 4 2 5 1 6		F4	3 2 4 1 5 6		F4	3 2 1 4 6 5		F4	3 2 4 5 1 6
	F5	3 4 2 5 1 6		F5	3 4 2 1 5 6		F5	3 2 4 5 1 6		F5	3 2 4 1 5 6
I5	F1	6 3 4 5 2 1	I6	F1	3 4 2 6 5 1	I7	F1	3 4 6 2 1 5	I8	F1	3 6 4 2 5 1
	F2	4 5 2 6 1 3		F2	3 4 2 6 5 1		F2	3 4 5 6 2 1		F2	3 4 2 6 1 5
	F3	3 4 6 2 5 1		F3	4 3 2 5 1 6		F3	3 4 2 6 5 1		F3	3 4 2 6 5 1
	F4	3 4 5 2 6 1		F4	3 4 2 5 6 1		F4	3 4 2 6 1 5		F4	3 4 2 6 5 1
	F5	3 4 2 5 1 6		F5	4 3 2 1 5 6		F5	3 4 2 5 6 1		F5	3 4 2 6 5 1

Table 8. Significant *a posteriori* Test Results--Order/Frequency/Intensity Interaction (5% Level of Significance): Order Relationships

	Intensity 1	Intensity 2	Intensity 3	Intensity 4
Frequency 1	06,2 > 4	02 > 6 02 > 3 02 > 4 02 > 1	02,1 > 3 02 > 6	02,1,4,5,6 > 3
Frequency 2	02 > 3	04,2,1,5 > 3	02,1,6,5,4 > 3	01,2,4,6,5 > 3
Frequency 3	01,6,2 > 3	01 > 3	02,1,4,5,6 > 3	01 > 3 01 > 5 01 > 6 01 > 2
Frequency 4	06,1,5,2 > 3 06,1,2 > 4	06,5,1,4 > 3 06,5,1,4 > 2 06,5 > 4 06 > 1 06 > 5	05,6 > 3	06,1,5,4 > 3 06 > 2 06 > 4 06 > 5 06 > 1
Frequency 5	06,1,5,2 > 3 06,1,5 > 4 06,1 > 2 06 > 5 06 > 1	06,5,1,2,4 > 3 06 > 4 06 > 1 06 > 5	06,1,5,4,2 > 3 06,1,5 > 2 06 > 4	06,5,1,4,2 > 3 06 > 2 06 > 4 06 > 1 06 > 5

Table 8. extended

	Intensity 5	Intensity 6	Intensity 7	Intensity 8
Frequency 1	--	01,5,6 > 3	05,1,2 > 3 05,1 > 4	01,5,2 > 3 01,5,2 > 6 01,5,2 > 4
Frequency 2	--	01,5 > 3 01,5 > 4 01 > 2 01 > 6	01,2,6,5 > 3 01,2,6,5 > 4	05,1,6,2 > 3 05,1 > 4 05,1 > 2 05,1 > 6
Frequency 3	01,6,2,5,4 > 3	06 > 4	01,5,6,2 > 3 01,5,2 > 4	01,5 > 3 01,5 > 4 01,5 > 2 01,5 > 6
Frequency 4	01,6,2,5,4 > 3	01,5,6 > 3 01,5,6 > 4 01,5,6 > 2	05,1,6 > 3 05,1 > 4 05,1 > 2	01,5,6,2 > 3 01,5,6 > 4 01,5 > 2 01,5 > 6
Frequency 5	06,1,5,2,4 > 3 06,1 > 4 06 > 2	06 > 4	01,6,5 > 3 01,6,5 > 4 01,6,5 > 2	01,5,6,2 > 3 01,5,6 > 4 01,5 > 2

Table 9. Order/Intensity/Frequency Factor Ordering, Low to High

		Frequency
01	I1	1 2 3 4 5
	I2	1 2 4 3 5
	I3	3 1 4 2 5
	I4	1 2 5 3 4
	I5	2 1 3 4 5
	I6	1 5 3 4 2
	I7	2 3 1 4 5
	I8	1 2 3 5 4
04	I1	1 2 3 4 5
	I2	1 3 4 5 2
	I3	3 1 2 4 5
	I4	1 2 3 5 4
	I5	1 2 4 3 5
	I6	4 2 1 3 5
	I7	2 3 1 4 5
	I8	4 1 3 5 2

		Frequency
02	I1	1 3 2 5 4
	I2	4 1 3 2 5
	I3	4 3 5 1 2
	I4	2 5 3 4 1
	I5	2 1 3 4 5
	I6	1 4 3 2 5
	I7	2 3 4 5 1
	I8	4 3 2 1 5
05	I1	1 2 3 4 5
	I2	1 3 2 5 4
	I3	3 1 2 4 5
	I4	1 2 3 5 4
	I5	2 4 1 3 5
	I6	1 3 5 4 2
	I7	2 3 1 4 5
	I8	1 3 2 4 5

		Frequency
03	I1	1 2 3 4 5
	I2	1 4 3 5 2
	I3	3 1 2 5 4
	I4	1 2 5 3 4
	I5	3 4 5 1 2
	I6	1 4 2 3 5
	I7	2 3 1 4 5
	I8	4 1 2 5 3
06	I1	1 2 3 4 5
	I2	1 2 3 4 5
	I3	1 3 4 2 5
	I4	1 2 3 5 4
	I5	1 3 2 4 5
	I6	1 2 3 4 5
	I7	2 1 3 4 5
	I8	1 3 2 4 5

Table 10. Significant *a posteriori* Test Results--Order/Frequency/Intensity Interaction (5% Level of Significance): Frequency Relationships

	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6
Intensity 1	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3	F4,5,2,3 > 1	F5,4, > 1	F5,4,3,2 > 1	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3	F5,4,3 > 1 F5,4,3 > 2 F5,4 > 3 F5 > 4
Intensity 2	F5,4,3,2 > 1	F5,2 > 4	--	F2,5,4,3 > 1	F4,5,2 > 1 F4,5 > 3 F5 > 2	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3
Intensity 3	F5 > 3 F5 > 1 F5 > 4 F5 > 2	--	--	F5 > 3 F5 > 1	F5 > 3 F5 > 1 F5 > 2 F5 > 4	F5,2,4 > 1 F5,4 > 3 F5 > 4 F5 > 2
Intensity 4	F4,3 > 1	--	F4,3,5 > 1 F4 > 2	--	F4,5,3 > 1 F4,5 > 2 F5 > 3	F4,5 > 1 F4,5 > 2 F4,5 > 3
Intensity 5	--	--	F2 > 3 F2 > 4 F2 > 5 F2 > 1	--	F5 > 2	F5,4,2 > 1 F5 > 3 F5 > 2 F5 > 4
Intensity 6	F2,4 > 1	--	F5 > 1 F5 > 4	--	--	F5,4 > 1
Intensity 7	F5,4 > 2 F5 > 1	--	--	F5 > 2	F5,4,1,3 > 2	F5 > 2 F5 > 1 F5 > 3 F5 > 4
Intensity 8	--	--	--	--	--	F5,4,3 > 1

Table 11. Order/Frequency/Intensity Factor Ordering, Low to High

		Intensity
01	F1	1 2 3 4 5 6 7 8
	F2	1 2 3 4 5 7 6 8
	F3	1 3 2 4 5 6 7 8
	F4	1 2 3 4 5 6 7 8
	F5	1 2 3 4 5 6 7 8
04	F1	1 2 3 4 5 6 7 8
	F2	1 3 2 4 5 7 6 8
	F3	1 2 3 4 5 6 7 8
	F4	1 2 3 5 4 6 7 8
	F5	1 2 3 4 5 6 7 8

		Intensity
02	F1	1 2 3 4 5 6 7 8
	F2	1 2 3 4 5 6 7 8
	F3	1 2 3 4 5 6 7 8
	F4	2 1 3 4 5 6 7 8
	F5	1 2 3 4 5 6 7 8
05	F1	1 2 3 4 5 6 7 8
	F2	1 2 3 4 5 7 6 8
	F3	1 2 3 4 5 6 7 8
	F4	1 3 2 5 4 6 7 8
	F5	1 2 3 4 5 6 7 8

		Intensity
03	F1	1 2 3 4 5 6 7 8
	F2	1 2 3 4 7 5 6 8
	F3	1 3 2 5 4 7 6 8
	F4	1 2 3 5 4 6 7 8
	F5	1 2 3 4 5 7 6 8
06	F1	1 2 3 4 5 6 7 8
	F2	1 2 3 4 5 7 6 8
	F3	1 2 3 4 5 7 6 8
	F4	1 3 2 5 4 6 7 8
	F5	1 2 3 4 5 6 7 8

Table 12. Significant *a posteriori* Test Results--Order/Frequency/Intensity Interaction (5% Level of Significance): Intensity Relationships

	Order 1		Order 2		Order 3	
Frequency 1	I8,7,6,5,4,3,2	> 1	I8,7,6,5,4,3,2	> 1	I8,7,6,5,4,3,2	> 1
	I8,7,6,5,4,3	> 2	I8,7,6,5,4	> 2	I8,7,6,5,4	> 2
	I8,7,6,5,4	> 3	I8,7,6,5,4	> 3	I8,7,6,5	> 3
	I8,7,6,5	> 4	I8,7	> 4	I8,7,6,5	> 4
	I8,7,6	> 5	I8,7	> 5	I8,7	> 5
	I8,7	> 6	I8,7	> 6	I8,7	> 6
	I8	> 7				
Frequency 2	I8,6,7,5,4,3,2	> 1	I8,7,6,5,4,3,2	> 1	I8,6,5,7,4,3,2	> 1
	I8,6,7,5,4	> 2	I8,7,6,5	> 2	I8,6,5,7	> 2
	I8,6,7,5,4	> 3	I8,7,6,5	> 3	I8,6,5,7	> 3
	I8,6,7	> 4	I8,7,6	> 4	I8,6,5,7	> 4
	I8,6,7	> 5	I8,7,6	> 5	I8	> 7
	I8	> 7	I8	> 6	I8	> 6
	I8	> 6	I8	> 7		
Frequency 3	I8,7,6,5,4,2,3	> 1	I8,7,6,5,4,3,2	> 1	I8,6,7,4,5,2,3	> 1
	I8,7,6,5,4	> 3	I8,7,6,5,4	> 2	I8,6,7,4,5	> 3
	I8,7,6,5,4	> 2	I8,7,6,5,4	> 3	I8,6,7,4,5	> 2
	I8,7,6	> 4	I8,7,6	> 4	I8,6,7	> 5
	I8,7,6	> 5	18,7	> 5	I8,6,7	> 4
	I8	> 6	I8	> 6	I8	> 7
	I8	> 7			I8	> 6
Frequency 4	I8,7,6,5,4	> 1	I8,7,6,5,4	> 2	I8,7,6,4,5,3	> 1
	I8,7,6,5,4	> 2	I8,7,6,5,4	> 1	I8,7,6,4,5	> 2
	I8,7,6,5,4	> 3	I8,7,6,5,4	> 3	I8,7,6,4,5	> 3
	I8,7,6	> 4	I8,7	> 4	I8,7,6	> 5
	I8,7,6	> 5	I8,7	> 5	I8,7,6	> 4
	I8	> 6	I8	> 6		
	I8	> 7				
Frequency 5	I8,7,6,5,4,3	> 1	I8,7,6,5,4,3,2	> 1	I8,6,7,5,4	> 1
	I8,7,6,5,4,3	> 2	I8,7,6,5,4	> 2	I8,6,7,5,4	> 2
	I8,7,6,5	> 3	I8,7,6,5,4	> 3	I8,6,7,5,4	> 3
	I8,7,6,5	> 4	I8,7,6,5	> 4	I8,6,7	> 4
	I8,7	> 5	I8,7	> 5	I8,6,7	> 5
	I8,7	> 6	I8	> 6		
			I8	> 7		

Table 12. extended

	Order 4	Order 5	Order 6
Frequency 1	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4,3 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7 > 5 I8 > 6	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4,3 > 2 I8,7,6,5,4 > 3 I8,7,6,5 > 4 I8,7 > 5 I8,7 > 6	I8,7,6,5,4,3 > 1 I8,7,6,5,4,3 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5
Frequency 2	I8,6,7,5,4,2,3 > 1 I8,6,7,5 > 3 I8,6,7,5 > 2 I8,6 > 4 I8 > 5 I8 > 7 I8 > 6	I8,6,7,5,4,3,2 > 1 I8,6,7,5,4 > 2 I8,6,7,5 > 3 I8,6,7 > 4 I8,6,7 > 5 I8 > 7 I8 > 6	I8,6,7,5,4,3,2 > 1 I8,6,7,5,4,3 > 2 I8,6,7,5 > 3 I8,6,7,5 > 4 I8,6,7 > 5 I8 > 7 I8 > 6
Frequency 3	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8 > 4 I8 > 5 I8 > 6 I8 > 7	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6,5 > 4 I8,7 > 5 I8,7 > 6 I8 > 7	I8,6,7,5,4 > 1 I8,6,7,5,4 > 2 I8,6,7,5,4 > 3 I8,6,7 > 4 I8,6,7 > 5
Frequency 4	I8,7,6,4,5,3,2 > 1 I8,7,6,4,5 > 2 I8,7,6,4,5 > 3 I8,7 > 5 I8,7 > 4 I8,7 > 6	I8,7,6,4,5,2,3 > 1 I8,7,6,4,5 > 3 I8,7,6,4,5 > 2 I8,7,6 > 5 I8,7,6 > 4 I8,7 > 6	I8,7,6,4,5,2 > 1 I8,7,6,4,5,2 > 3 I8,7,6,4 > 2 I8,7,6,4 > 5 I8 > 4
Frequency 5	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4,3 > 2 I8,7,6,4 > 3 I8,7 > 4 I8,7 > 5 I8 > 6	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5 > 3 I8,7,6 > 4 I8,7 > 5 I8,7 > 6	I8,7,6,5,4 > 1 I8,7,6,5 > 2 I8,7,6,5 > 3 I8,7 > 4 I8,7 > 5 I8,7 > 6

Table 13. Task/Frequency/Intensity Interaction--
Mean Log Judgement Values

Task 1

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.276	1.557	1.740	1.969	2.029	2.167	2.322	2.496
	2	1.417	1.722	1.772	1.938	2.070	2.282	2.187	2.481
F	3	1.474	1.626	1.681	1.982	1.968	2.181	2.270	2.485
	4	1.580	1.686	1.726	2.009	1.973	2.181	2.306	2.430
	5	1.632	1.719	1.824	1.970	2.057	2.191	2.325	2.435

Task 2

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.147	1.460	1.719	1.944	2.030	2.215	2.398	2.502
	2	1.308	1.692	1.763	1.906	2.051	2.260	2.232	2.477
F	3	1.383	1.613	1.656	1.964	2.026	2.200	2.258	2.482
	4	1.431	1.562	1.649	1.965	1.971	2.187	2.358	2.431
	5	1.461	1.587	1.726	1.884	2.060	2.174	2.360	2.472

Task 3

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.550	1.626	1.655	1.672	1.828	1.821	1.949	1.898
	2	1.685	1.749	1.805	1.771	1.900	1.949	1.957	2.043
F	3	1.750	1.822	1.743	1.884	1.965	2.047	2.030	2.061
	4	1.896	1.986	1.915	2.126	2.065	2.106	2.090	2.147
	5	2.030	2.120	2.105	2.126	2.113	2.174	2.205	2.229

Table 14. Intensity/Frequency/Task Factor Ordering, Low to High

		Task		
I1	F1	2	1	3
	F2	2	1	3
	F3	2	1	3
	F4	2	1	3
	F5	2	1	3
I5	F1	3	1	2
	F2	3	2	1
	F3	3	1	2
	F4	2	1	3
	F5	1	2	3

		Task		
I2	F1	2	1	3
	F2	2	1	3
	F3	2	1	3
	F4	2	1	3
	F5	2	1	3
I6	F1	3	1	2
	F2	3	2	1
	F3	3	1	2
	F4	3	1	2
	F5	2	3	1

		Task		
I3	F1	3	2	1
	F2	2	1	3
	F3	2	1	3
	F4	2	1	3
	F5	2	1	3
I7	F1	3	1	2
	F2	3	1	2
	F3	3	2	1
	F4	3	1	2
	F5	3	1	2

		Task		
I4	F1	3	2	1
	F2	3	2	1
	F3	3	2	1
	F4	2	1	3
	F5	2	1	3
I8	F1	3	1	2
	F2	3	2	1
	F3	3	2	1
	F4	3	1	2
	F5	3	1	2

Table 15. Significant a posteriori Test Results--Task/Frequency/Intensity Interaction (5% Level of Significance): Task Relationships

	Intensity 1	Intensity 2	Intensity 3	Intensity 4
Frequency 1	T3,1 > 2 T3 > 1	T3,1 > 2	--	T1,2 > 3
Frequency 2	T3,1 > 2 T3 > 1	--	--	T1,2 > 3
Frequency 3	T3,1 > 2 T3 > 1	T3 > 2 T3 > 1	--	T1,2 > 3
Frequency 4	T3,1 > 2 T3 > 1	T3,1 > 2 T3 > 1	T3,1 > 2 T3 > 1	T3 > 2 T3 > 1
Frequency 5	T3,1 > 2 T3 > 1	T3,1 > 2 T3 > 1	T3,1 > 2 T3 > 1	T3,1 > 2 T3 > 1

	Intensity 5	Intensity 6	Intensity 7	Intensity 8
Frequency 1	T2,1 > 3	T2,1 > 3	T2,1 > 3 T2 > 1	T2,1 > 3
Frequency 2	T1,2 > 3	T1,2 > 3	T2,1 > 3	T1,2 > 3
Frequency 3	--	T2,1 > 3	T1,2 > 3	T1,2 > 3
Frequency 4	T3 > 2 T3 > 1	T1 > 3	T2,1 > 3	T2,1 > 3
Frequency 5	--	--	T2,1 > 3	T2,1 > 3

intensities 4 and 5. Task 3 is significantly smaller at the low and greater at the high frequencies at intensities 4 and 5. Tasks 1 and 2 differ only at the lower intensities and higher frequencies. Factor ordering for frequency is presented in Table 16 with the significant comparisons listed in Table 17. It will be noted that the main frequency effects were within task 3 (P) as would be expected, but that both tasks 1 and 2 show significant frequency differences at the lower and two of the higher intensities. Intensity ordering appears in Table 18 with significant comparisons listed in Table 19.

Mean log judgement values for the task/order/intensity interaction appear as Table 20. Task ordering appears as Table 21 and significant (5% level of significance) comparisons appear in Table 22. It is apparent again that task 3 (P) is significantly larger than and smaller than the other tasks at the low and high intensities respectively. In but two instances were tasks 1 and 2 significantly different (both in order 6: PLE). Little or no task difference is found in orders 2 and 3 (EPL and LPE), or at the middle intensities. The ordering for the factor, order, is given in Table 23 and the significant comparisons in Table 24. Most of the significant order differences lie within task 1 (E) and at the higher or lower intensity levels. Intensity ordering is given as Table 25 and the significant comparisons as Table 26. Within task 3 (P) only orders 2 and 3 (EPL and LPE) show several significant differences between intensities.

Two-way Interactions

The frequency/intensity interaction means appear as Table 27, with Table 28 providing ordering for both factors, and Table 29 listing the significant (5% level of significance) comparisons, separated by factor.

Table 16. Task/Intensity/Frequency Factor Ordering, Low to High

		Frequency				
T1	I1	1	2	3	4	5
	I2	1	3	4	5	2
	I3	3	4	1	2	5
	I4	2	1	5	3	4
	I5	3	4	1	5	2
	I6	1	3	4	5	2
	I7	2	3	4	1	5
	I8	4	5	2	3	1

		Frequency				
T2	I1	1	2	3	4	5
	I2	1	4	5	3	2
	I3	4	3	1	5	2
	I4	5	2	1	3	4
	I5	4	3	1	2	5
	I6	5	4	3	1	2
	I7	2	3	4	5	1
	I8	4	5	2	3	1

		Frequency				
T3	I1	1	2	3	4	5
	I2	1	2	3	4	5
	I3	1	3	2	4	5
	I4	1	2	3	5	4
	I5	1	2	3	4	5
	I6	1	2	3	4	5
	I7	1	2	3	4	5
	I8	1	2	3	4	5

Table 17. Significant *a posteriori* Test Results--Task/Frequency/Intensity Interaction (5% Level of Significance): Frequency Relationships

	Task 1	Task 2	Task 3
Intensity 1	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3	F5,4,3,2 > 1 F5,4,3 > 2	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3 F5 > 4
Intensity 2	F2,5,4 > 1 F5 > 3	F2,3,5,4 > 1 F2 > 4 F2 > 5 F2 > 3	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3 F5 > 4
Intensity 3	F5 > 3	F2 > 4 F2 > 3	F5,4,2,3 > 1 F5,4 > 3 F5,4 > 2 F5 > 4
Intensity 4	--	--	F4,5,3,2 > 1 F4,5,3 > 2 F4,5 > 3
Intensity 5	--	--	F5,4,3 > 1 F5,4 > 2 F5,4 > 3
Intensity 6	F2 > 1 F2 > 3 F2 > 4 F2 > 5	--	F5,4,3,2 > 1 F5,4,3 > 2 F5 > 3
Intensity 7	F5,1,4,3 > 2	F1,5,4 > 2 F1,5,4 > 3	F5,4 > 1 F5,4 > 2 F5 > 3 F5 > 4
Intensity 8	--	--	F5,4,3,2 > 1 F5,4 > 2 F5,4 > 3 F5 > 4

Table 18. Task/Frequency/Intensity Factor Ordering, Low to High

		Intensity							
T1	F1	1	2	3	4	5	6	7	8
	F2	1	2	3	4	5	7	6	8
	F3	1	2	3	5	4	6	7	8
	F4	1	2	3	5	4	6	7	8
	F5	1	2	3	4	5	6	7	8
T2	F1	1	2	3	4	5	6	7	8
	F2	1	2	3	4	5	7	6	8
	F3	1	2	3	4	5	6	7	8
	F4	1	2	3	4	5	6	7	8
	F5	1	2	3	4	5	6	7	8
T3	F1	1	2	3	4	6	5	8	7
	F2	1	2	4	3	5	6	7	8
	F3	3	1	2	4	5	7	6	8
	F4	1	3	2	5	7	6	4	8
	F5	1	3	2	5	4	6	7	8

Table 19. Significant *a posteriori* Test Results--Task/Frequency/Intensity Interaction (5% Level of Significance): Intensity Relationships

	Task 1		Task 2		Task 3	
Frequency 1	I8,7,6,5,4,3,2	> 1	I8,7,6,5,4,3,2	> 1	I7,8,5,6,4,3,2	> 1
	I8,7,6,5,4,3	> 2	I8,7,6,5,4,3	> 2	I7,8,5,6	> 2
	I8,7,6,5,4	> 3	I8,7,6,5,4	> 3	I7,8,5,6	> 3
	I8,7,6	> 4	I8,7,6,5	> 4	I7,8,5,6	> 4
	I8,7,6	> 5	I8,7,6	> 5	I7	> 6
	I8,7	> 6	I8,7	> 6	I7	> 5
	I8	> 7	I8	> 7		
Frequency 2	I8,6,7,5,4,3,2	> 1	I8,6,7,5,4,3,2	> 1	I8,7,6,5,3	> 1
	I8,6,7,5,4	> 2	I8,6,7,5,4	> 2	I8,7,6,5	> 2
	I8,6,7,5,4	> 3	I8,6,7,5,4	> 3	I8,7,6,5	> 4
	I8,6,7,5	> 4	I8,6,7,5	> 4	I8,7,6,5	> 3
	I8,6,7	> 5	I8,6,7	> 5	I8	> 5
	I8,6	> 7	I8	> 7	I8	> 6
	I8	> 6	I8	> 6	I8	> 7
Frequency 3	I8,7,6,4,5,3,2	> 1	I8,7,6,5,4,3,2	> 1	I8,6,7,5,4	> 3
	I8,7,6,4,5	> 2	I8,7,6,5,4	> 2	I8,6,7,5,4	> 1
	I8,7,6,4,5	> 3	I8,7,6,5,4	> 3	I8,6,7,5	> 2
	I8,7,6	> 5	I8,7,6	> 4	I8,6,7,5	> 4
	I8,7,6	> 4	I8,7,6	> 5		
	I8,7	> 6	I8	> 6		
	I8	> 7	I8	> 7		
Frequency 4	I8,7,6,4,5,3,2	> 1	I8,7,6,5,4,3,2	> 1	I8,4,6,7,5	> 1
	I8,7,6,4,5	> 2	I8,7,6,5,4,3	> 2	I8,4,6,7,5	> 3
	I8,7,6,4,5	> 3	I8,7,6,5,4	> 3	I8,4,6,7,5	> 2
	I8,7,6	> 5	I8,7,6	> 4		
	I8,7,6	> 4	I8,7,6	> 5		
	I8,7	> 6	I8,7	> 6		
	I8	> 7				
Frequency 5	I8,7,6,5,4,3,2	> 1	I8,7,6,5,4,3,2	> 1	I8,7,6	> 1
	I8,7,6,5,4,3	> 2	I8,7,6,5,4,3	> 2	I8	> 3
	I8,7,6,5,4	> 3	I8,7,6,5,4	> 3	I8	> 2
	I8,7,6,5	> 4	I8,7,6,5	> 4	I8	> 5
	I8,7,6	> 5	I8,7,6	> 5		
	I8,7	> 6	I8,7	> 6		
	I8	> 7	I8	> 7		

Table 20. Task/Order/Intensity Interaction--
Mean Log Judgement Values

Task 1

		Intensity							
		1	2	3	4	5	6	7	8
O	1	1.396	1.576	1.711	2.085	2.144	2.407	2.554	2.844
	2	1.591	1.652	1.781	1.972	2.037	2.156	2.244	2.372
	3	1.482	1.596	1.633	1.784	1.870	2.032	2.046	2.203
	4	1.236	1.620	1.730	1.966	2.000	2.062	2.133	2.278
	5	1.400	1.611	1.734	1.920	2.010	2.253	2.376	2.613
	6	1.768	1.915	1.905	2.115	2.055	2.295	2.339	2.483

Task 2

		Intensity							
		1	2	3	4	5	6	7	8
O	1	1.344	1.635	1.774	1.984	2.109	2.294	2.448	2.683
	2	1.479	1.684	1.736	1.925	2.023	2.213	2.227	2.348
	3	1.296	1.482	1.624	1.815	1.920	2.118	2.192	2.247
	4	1.197	1.486	1.645	1.923	1.954	2.097	2.215	2.374
	5	1.467	1.695	1.737	1.931	2.069	2.263	2.447	2.656
	6	1.294	1.515	1.700	2.018	2.090	2.340	2.399	2.529

Task 3

		Intensity							
		1	2	3	4	5	6	7	8
O	1	2.004	2.001	1.954	1.924	1.993	1.991	2.000	2.016
	2	1.650	1.813	1.826	1.966	2.026	2.069	2.164	2.222
	3	1.494	1.631	1.586	1.755	1.864	1.980	1.946	2.044
	4	1.960	1.967	1.964	1.978	1.971	2.006	2.016	2.030
	5	1.792	1.909	1.938	1.990	2.028	2.071	2.123	2.155
	6	1.795	1.831	1.799	1.883	1.963	1.999	2.027	1.986

Table 21. Intensity/Order/Task Factor Ordering, Low to High

		Task		
I1	01	2	1	3
	02	2	1	3
	03	2	1	3
	04	2	1	3
	05	1	2	3
	06	2	1	3
I5	01	3	2	1
	02	2	3	1
	03	3	2	1
	04	2	3	1
	05	1	3	2
	06	3	1	2

		Task		
I2	01	1	2	3
	02	1	2	3
	03	2	1	3
	04	2	1	3
	05	1	2	3
	06	2	3	1
I6	01	3	2	1
	02	3	2	1
	03	3	1	2
	04	3	2	1
	05	3	2	1
	06	3	1	2

		Task		
I3	01	1	2	3
	02	2	1	3
	03	3	2	1
	04	2	1	3
	05	1	2	3
	06	2	3	1
I7	01	3	2	1
	02	3	2	1
	03	3	1	2
	04	3	1	2
	05	3	1	2
	06	3	1	2

		Task		
I4	01	3	2	1
	02	2	3	1
	03	3	1	2
	04	2	1	3
	05	1	2	3
	06	3	2	1
I8	01	3	2	1
	02	3	2	1
	03	3	1	2
	04	3	1	2
	05	3	1	2
	06	3	1	2

Table 22. Significant *a posteriori* Test Results--Task/Order/Intensity Interaction (5% Level of Significance): Task Relationships

	Intensity 1	Intensity 2	Intensity 3	Intensity 4
Order 1	T3 > 2 T3 > 1	T3 > 1 T3 > 2	T3 > 1	--
Order 2	--	--	--	--
Order 3	T1 > 2	--	--	--
Order 4	T3 > 2 T3 > 1	T3 > 2 T3 > 1	T3 > 2 T3 > 1	--
Order 5	T3 > 1 T3 > 2	T3 > 1 T3 > 2	T3 > 2	--
Order 6	T3,1 > 2	T1,3 > 2	--	T1 > 3

	Intensity 5	Intensity 6	Intensity 7	Intensity 8
Order 1	--	T1 > 3 T2 > 3	T1 > 3 T2 > 3	T1 > 3 T2 > 3
Order 2	--	--	--	--
Order 3	--	--	T2 > 3	--
Order 4	--	--	--	T2 > 3 T1 > 3
Order 5	--	T1 > 3 T2 > 3	T2 > 3 T1 > 3	T2 > 3 T1 > 3
Order 6	--	T2 > 3 T1 > 3	T2 > 3 T1 > 3	T2 > 3 T1 > 3

Table 23. Task/Intensity/Order Factor Ordering, Low to High

		Order					
T1	I1	4	1	5	3	2	6
	I2	1	3	5	4	2	6
	I3	3	1	4	5	2	6
	I4	3	5	4	2	1	6
	I5	3	4	5	2	6	1
	I6	3	4	2	5	6	1
	I7	3	4	2	6	5	1
	I8	3	4	2	6	5	1
T2	I1	4	6	3	1	5	2
	I2	3	4	6	1	2	5
	I3	3	4	6	2	5	1
	I4	3	4	2	5	1	6
	I5	3	4	2	5	6	1
	I6	4	3	2	5	1	6
	I7	3	4	2	6	5	1
	I8	3	2	4	6	5	1
T3	I1	3	2	5	6	4	1
	I2	3	2	6	5	4	1
	I3	3	6	2	5	1	4
	I4	3	6	1	2	4	5
	I5	3	6	4	1	2	5
	I6	3	1	6	4	2	5
	I7	3	1	4	6	5	2
	I8	6	1	4	3	5	2

Table 24. Significant a posteriori Test Results--Task/Order/Intensity Interaction (5% Level of Significance): Order Relationships

	Task 1	Task 2	Task 3
Intensity 1	06,2 > 4 06 > 1 06 > 5 06 > 3	02,5 >4	01,4,6,5 > 3 01,4 > 2
Intensity 2	06 > 1 06 > 3 06 > 5 06 > 4 06 > 2	--	01,4,5 > 3
Intensity 3	--	--	04,1,5,2,6 > 3
Intensity 4	06,1 > 3	--	--
Intensity 5	01 > 3	--	--
Intensity 6	01,6 > 3 01 > 4 01 > 2	--	--
Intensity 7	01,5,6 > 3 01 > 4 01 > 2	05 >3 05 >2	--
Intensity 8	01,5,6 > 3 01,5 > 4 01,5 > 2 01 > 6 01 > 5	01,5,6 >3 01,5 >2 01,5 >4	--

Table 25. Task/Order/Intensity Factor Ordering, Low to High

		Intensity							
T1	01	1	2	3	4	5	6	7	8
	02	1	2	3	4	5	6	7	8
	03	1	2	3	4	5	6	7	8
	04	1	2	3	4	5	6	7	8
	05	1	2	3	4	5	6	7	8
	06	1	3	2	5	4	6	7	8
T2	01	1	2	3	4	5	6	7	8
	02	1	2	3	4	5	6	7	8
	03	1	2	3	4	5	6	7	8
	04	1	2	3	4	5	6	7	8
	05	1	2	3	4	5	6	7	8
	06	1	2	3	4	5	6	7	8
T3	01	4	3	6	5	7	2	1	8
	02	1	2	3	4	5	6	7	8
	03	1	3	2	4	5	7	6	8
	04	1	3	2	5	4	6	7	8
	05	1	2	3	4	5	6	7	8
	06	1	3	2	4	5	8	6	7

Table 26. Significant a posteriori Test Results--Task/Order/ Intensity Interaction (5% Level of Significance): Intensity Relationships

	Task 1	Task 2	Task 3
Order 1	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5 I8 > 6 I8 > 7	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5 I8 > 6 I8 > 7	--
Order 2	I8,7,6,5,4 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7 > 4 I8 > 5 I8 > 6	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7 > 4 I8 > 5	I8,7,6,5,4 > 1 I8,7 > 2 I8,7 > 3
Order 3	I8,7,6,5,4 > 1 I8,7,6,5 > 2 I8,7,6,5 > 3 I8,7,6 > 4 I8 > 5	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5	I8,7,6,5,4 > 1 I8,7,6,5 > 3 I8,7,6,5 > 2 I8 > 4
Order 4	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8 > 4 I8 > 5	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7 > 4 I8,7 > 5 I8 > 6	--
Order 5	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5 I8 > 6 I8 > 7	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5 I8 > 6 I8 > 7	I8,7,6 > 1
Order 6	I8,7,6,4,5 > 1 I8,7,6 > 3 I8,7,6 > 2 I8,7,6 > 5 I8 > 4	I8,7,6,5,4,3,2 > 1 I8,7,6,5,4 > 2 I8,7,6,5,4 > 3 I8,7,6 > 4 I8,7,6 > 5	--

Table 27. Frequency/Intensity Interaction--
Mean Log Judgement Values

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.324	1.548	1.705	1.862	1.962	2.068	2.223	2.299
	2	1.470	1.721	1.780	1.872	2.007	2.164	2.125	2.334
F	3	1.536	1.687	1.693	1.943	1.987	2.142	2.186	2.343
	4	1.636	1.744	1.763	2.034	2.003	2.158	2.251	2.336
	5	1.707	1.805	1.885	1.993	2.077	2.180	2.297	2.379

Table 28. Frequency/Intensity Factor Ordering, Low to High

	Intensity							
F1	1	2	3	4	5	6	7	8
F2	1	2	3	4	5	7	6	8
F3	1	2	3	4	5	6	7	8
F4	1	2	3	5	4	6	7	8
F5	1	2	3	4	5	6	7	8

	Frequency				
I1	1	2	3	4	5
I2	1	3	2	4	5
I3	3	1	4	2	5
I4	1	2	3	5	4
I5	1	3	4	2	5
I6	1	3	4	2	5
I7	2	3	1	4	5
I8	1	2	3	4	5

Table 29. Significant *a posteriori* Test Results--Frequency/Intensity Interaction (5% Level of Significance)

a. Intensity

Frequency 1	I8,7,6,5,4,3,2	> 1	Frequency 2	I8,6,7,5,4,3,2	> 1
	I8,7,6,5,4,3	> 2		I8,6,7,5,4,3	> 2
	I8,7,6,5,4	> 3		I8,6,7,5,4	> 3
	I8,7,6,5	> 4		I8,6,7,5	> 4
	I8,7,6	> 5		I8,6,7	> 5
	I8,7	> 6		I8	> 7
	I8	> 7		I8	> 6
Frequency 3	I8,7,6,5,4,3,2	> 1	Frequency 4	I8,7,6,4,5,3,2	> 1
	I8,7,6,5,4	> 2		I8,7,6,4,5	> 2
	I8,7,6,5,4	> 3		I8,7,6,4,5	> 3
	I8,7,6	> 4		I8,7,6	> 5
	I8,7,6	> 5		I8,7,6	> 4
	I8	> 6		I8,7	> 6
	I8	> 7		I8	> 7
Frequency 5	I8,7,6,5,4,3,2	> 1			
	I8,7,6,5,4,3	> 2			
	I8,7,6,5,4	> 3			
	I8,7,6,5	> 4			
	I8,7,6	> 5			
	I8,7	> 6			
	I8	> 7			

b. Frequency

Intensity 1	F5,4,3,2	> 1	Intensity 5	F5	> 1
	F5,4,3	> 2		F5	> 3
	F5,4	> 3		F5	> 4
	F5	> 4		F5	> 2
Intensity 2	F5,4,2,3	> 1	Intensity 6	F5,2,4,3	> 1
	F5,4	> 3			
	F5	> 2			
	F5	> 4			
Intensity 3	F5,2,4	> 3	Intensity 7	F5,4,1,3	> 2
	F5,2,4	> 1		F5,4	> 3
	F5	> 4		F5	> 1
	F5	> 2		F5	> 4
Intensity 4	F4,5,3	> 1	Intensity 8	F5	> 1
	F4,5,3	> 2			
	F4,5	> 3			

Intensity differences are spread across all frequency levels but the frequency differences are concentrated more within the lower intensity levels.

Mean values for the task/intensity interaction are in Table 30, and Tables 31 and 32 provide factor ordering and significant (5% level of significance) comparisons for both factors. Intensity differences are fewer in task 3 (P) and task differences nil at the middle two intensity levels. Tasks 1 and 2 are again seen to differ only at the low intensities and task 3, again, is significantly larger at the low and smaller at the high intensities.

The order/frequency interaction mean values comprise Table 33, the ordering data, Table 34, and the significant (5% level of significance) comparisons Table 35. Orders 2 and 3 (EPL and LPE) show no frequency differences and order 4 (LEP) but a single significant frequency difference. Order differences do not present a pattern.

Task/frequency interaction means are given in Table 36, with ordering in Table 37 and significant (5% level of significance) comparisons in Table 38. Frequency differences, with one task 1 (E) exception, are all within task 3 (P). Task 3 is significantly smaller at low and greater at high frequencies with no difference at the center frequency.

One-way Interactions

Tables 39-42 present mean log judgement values for the four one-way interactions, i.e., the main effects. All factors are ordered in Table 43, and the significant (5% level of significance) comparisons are presented in Tables 44-46 for the individual factors. Intensity shows significant differences generally following the underlying physical

Table 30. Task/Intensity Interaction--
Mean Log Judgement Values

		Intensity							
		1	2	3	4	5	6	7	8
	1	1.476	1.662	1.749	1.974	2.019	2.201	2.282	2.466
T	2	1.346	1.583	1.703	1.933	2.028	2.207	2.321	2.473
	3	1.782	1.858	1.844	1.916	1.974	2.019	2.046	2.076

Table 31. Task/Intensity Factor Ordering, Low to High

	Intensity							
T1	1	2	3	4	5	6	7	8
T2	1	2	3	4	5	6	7	8
T3	1	3	2	4	5	6	7	8

	Task		
I1	2	1	3
I2	2	1	3
I3	2	1	3
I4	3	2	1
I5	3	1	2
I6	3	1	2
I7	3	1	2
I8	3	1	2

Table 32. Significant *a posteriori* Test Results--Task/Intensity Interaction (5% Level of Significance)

a. Intensity

Task 1	I8,7,6,5,4,3,2	> 1
	I8,7,6,5,4,3	> 2
	I8,7,6,5,4	> 3
	I8,7,6	> 4
	I8,7,6	> 5
	I8,7	> 6
	I8	> 7
Task 2	I8,7,6,5,4,3,2	> 1
	I8,7,6,5,4,3	> 2
	I8,7,6,5,4	> 3
	I8,7,6,5	> 4
	I8,7,6	> 5
	I8,7	> 6
	I8	> 7
Task 3	I8,7,6,5,4	> 1
	I8,7,6,5	> 3
	I8,7,6,5	> 2
	I8,7,6	> 4
	I8	> 5

b. Task

Intensity 1	T3,1	> 2
	T3	> 1
Intensity 2	T3,1	> 2
	T3	> 1
Intensity 3	T3	> 2
	T3	> 1
Intensity 4	--	
Intensity 5	--	
Intensity 6	T2,1	> 3
Intensity 7	T2,1	> 3
Intensity 8	T2,1	> 3

Table 33. Order/Frequency Interaction--
Mean Log Judgement Values

		Frequency				
		1	2	3	4	5
O	1	1.935	2.009	2.033	2.081	2.118
	2	1.941	1.969	1.956	1.948	1.998
	3	1.769	1.819	1.815	1.829	1.860
	4	1.837	1.900	1.906	1.929	1.971
	5	1.921	1.972	1.978	2.066	2.102
	6	1.840	1.934	1.950	2.091	2.194

Table 34. Order/Frequency Factor Ordering, Low to High

	Frequency				
01	1	2	3	4	5
02	1	4	3	2	5
03	1	3	2	4	5
04	1	2	3	4	5
05	1	2	3	4	5
06	1	2	3	4	5

	Order					
F1	3	4	6	5	1	2
F2	3	4	6	2	5	1
F3	3	4	6	2	5	1
F4	3	4	2	5	1	6
F5	3	4	2	5	1	6

Table 35. Significant *a posteriori* Test Results--Order/Frequency Interaction (5% Level of Significance)

a. Frequency

Order 1	F5,4,3	> 1
	F5	> 2
Order 2	--	
Order 3	--	
Order 4	F5	> 1
Order 5	F5,4	> 1
	F5,4	> 2
	F5,4	> 3
Order 6	F5,4,3,2	> 1
	F5,4	> 2
	F5,4	> 3
	F5	> 4

b. Order

Frequency 1	02,1,5	> 3
	02,1,5	> 6
Frequency 2	01,5,2,6,4	> 3
Frequency 3	01,5,2,6,4	> 3
	01	> 4
Frequency 4	06,1,5,4,2	> 3
	06,1,5	> 2
	06,1,5	> 4
Frequency 5	06,1,5,2,4	> 3
	06,1,5	> 4
	06,1,5	> 2
	06	> 5
	06	> 1

Table 36. Task/Frequency Interaction--
Mean Log Judgement Values

		Frequency				
		1	2	3	4	5
T	1	1.944	1.984	1.959	1.987	2.019
	2	1.927	1.961	1.948	1.944	1.965
	3	1.750	1.857	1.913	2.041	2.136

Table 37. Task/Frequency Factor Ordering, Low to High

	Frequency				
T1	1	3	2	4	5
T2	1	4	3	2	5
T3	1	2	3	4	5

	Task		
F1	3	2	1
F2	3	2	1
F3	3	2	1
F4	2	1	3
F5	2	1	3

Table 38. Significant *a posteriori* Test Results--Task/Frequency Interaction (5% Level of Significance)

a. Frequency

Task 1	F5	> 1
Task 2	--	
Task 3	F5,4,3,2	> 1
	F5,4,3	> 2
	F5,4	> 3
	F5	> 4

b. Task

Frequency 1	T1,2	> 3
Frequency 2	T1,2	> 3
Frequency 3	--	
Frequency 4	T3	> 2
	T3	> 1
Frequency 5	T3,1	> 2
	T3	> 1

Table 39. Mean Log Judgements for Task

1	2	3
1.978	1.949	1.940

Table 40. Mean Log Judgements for Order

1	2	3	4	5	6
2.035	1.962	1.818	1.909	2.008	2.002

Table 41. Mean Log Judgements for Frequency

1	2	3	4	5
1.873	1.934	1.940	1.991	2.040

Table 42. Mean Log Judgements for Intensity

1	2	3	4	5	6	7	8
1.535	1.701	1.765	1.941	2.007	2.142	2.216	2.338

Table 43. Factor Ordering, Low to High

Task:	3	2	1					
Order:	3	4	2	6	5	1		
Frequency:	1	2	3	4	5			
Intensity:	1	2	3	4	5	6	7	8

Table 44. Significant *a posteriori* Test Results--Intensity (5% Level of Significance)

8,7,6,5,4,3,2 > 1
8,7,6,5,4 > 2
8,7,6,5,4 > 3
8,7,6 > 4
8,7,6 > 5
8 > 6
8 > 7

Table 45. Significant *a posteriori* Test Results--Frequency (5% Level of Significance)

5,4,3,2 > 1
5,4 > 2
5,4 > 3
5 > 4

Table 46. Significant *a posteriori* Test Results--Order (5% Level of Significance)

1,5,6 > 3

actuality as does frequency. Order 3 (LPE) is significantly smaller than orders 6 (PLE), 5 (PEL) and 1 (ELP). Task did not significantly differ at the main effect level as noted in the analysis of variance summary (Table 4).

Main Effects

There is no underlying physical parameter to suggest that a particular task ordering (i.e., the factor, order) should statistically be either equal to or different from any other ordering. In this respect, order is unique because the structure of the current study is such that statistically significant differences should obtain (e.g., for intensity) and that in some instances they did not is important.

The frequencies utilized in the present study differ by a full tone. Excepting the tone-deaf person, if such actually exists, any listener should report by his judgement values for the pitch task that the five frequencies are indeed different. And, for the loudness task, the listener should report that the intensities differ since the physical stimuli differ by 5 dB steps, a ten-fold increase over the generally-accepted difference limen. To an extent the task differences are to be expected also, particularly between tasks 2 and 3 (L and P) since the reference base is common in numerical value (standardized to 100) and the range of intensities utilized (60-95 dB) represents nearly six physical doublings while the frequency range utilized constitutes less than one physical doubling (a four-tone range vs. six tones/octave). On the other hand, since all three tasks share a standard reference base, it would be expected that all three tasks would yield similar judgements from listeners for those frequencies and intensities near (in physical value) the stimulus utilized as a "standard."

Insofar as task itself is concerned, the focus of this study is on the percept of vocal effort and the effect(s) of controlled intensity and frequency changes thereupon. While the two tasks, loudness and pitch, are not considered trivial, they will be neglected except as they provide insight into the effort percept.

Intensity

The intensity mean log judgement values of Table 42 are presented graphically in Figure 4. The pervasive effect of the physical energy difference is readily apparent in this figure although somewhat less than three judgement doublings are reported for the nearly six actual doublings. As suggested by the figure, I2-I3 were statistically equal as were the pair I4-I5 and the pair I6-I7, per Table 44. It should be noted that I5, the level used as a reference intensity level, yielded a judgement mean value of almost exactly 100, the normalized base level.

There is no striking discrepancy in the intensity relationships noted in the order/frequency/intensity interaction (Table 12), but when task is separated out as occurs in the task/frequency/intensity interaction (Table 19), the task/order/intensity interaction (Table 26), or the task/intensity interaction (Table 32), it becomes obvious that most of the intensity difference significances lie within tasks 1 and 2 (E and L) as would be expected. In Figure 5, a plot of the task/intensity mean log values from Table 30, the intensity contribution to tasks 1 and 2 may be seen. It should also be noted in Figure 5 that task 3 (P) was not free from intensity effect, as may be seen in the significant task/intensity comparisons of Table 32. When frequencies are examined individually as in the task/frequency/intensity interaction (Table 19) it

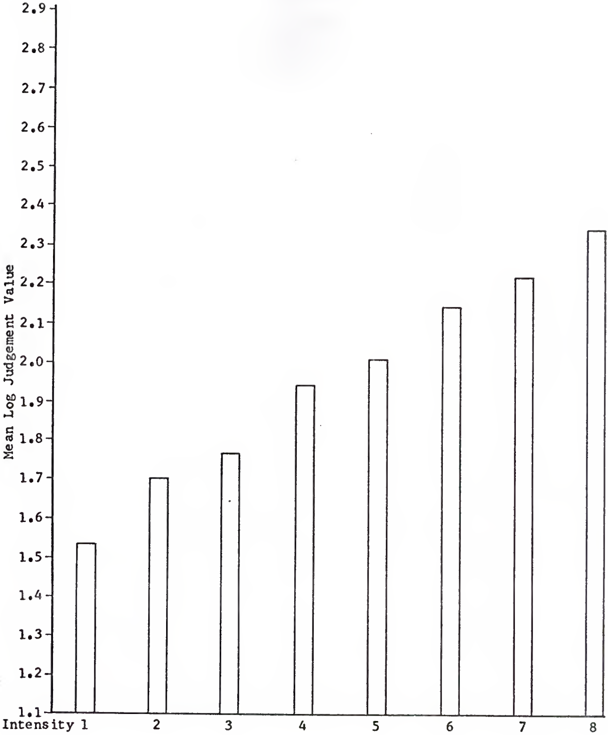


Figure 4. Intensity Main Effect

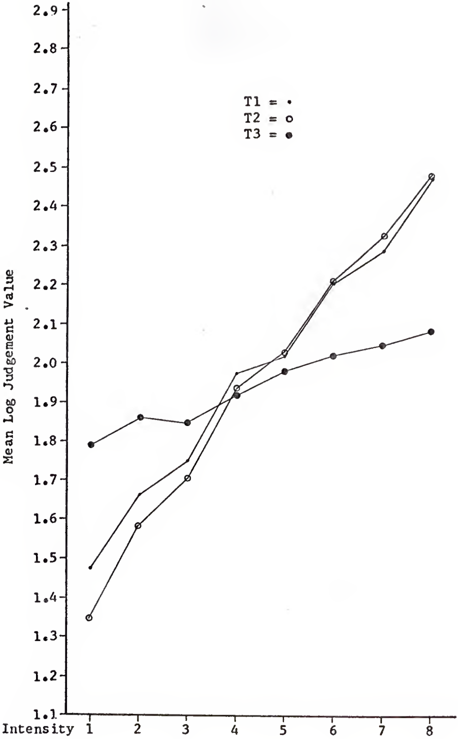


Figure 5. Task/Intensity Interaction by Task

may be seen that it is the two or three lower frequencies that show most of the intensity influence. In Figure 6, which plots the task 3 data from Table 19, it is apparent that while the intensity effect on frequency is greatest at the lower levels, it exists over all five frequencies.

Frequency

As evident in Table 45, F2-F3 were judged statistically equal at the one-way level. Figure 7 plots the frequency mean log data from Table 41 and shows a virtual physical as well as statistical equality. The range of overall frequency judgement values reflects the limited physical range of the stimuli. Frequency differences were mostly found in task 3 (P) as seen in the task/frequency interaction (Table 38), in orders 5 and 6 (PEL and PLE), evident in the order/frequency interaction (Table 35) and generally in the lower intensity levels as shown in the frequency/intensity interaction data in Table 29. When examining the three-way interaction level, however, it may be seen that frequency differences did appear within the other two tasks, mostly at the low intensities. At the two lowest intensities, F1 was judged both the softest and the least effortful stimulus. Frequency differences were far more prevalent within task 3, of course. In Table 10, the order/frequency/intensity interaction, the concentration of frequency differences within orders 5 and 6 and at low intensities is again evident.

Figure 8 plots the task/frequency interaction data from Table 36 and shows, as well as the frequency influence on task 3, the little overall influence on tasks 1 and 2. Figure 9 plots the frequency/intensity interaction from the mean data of Table 27 and shows clearly

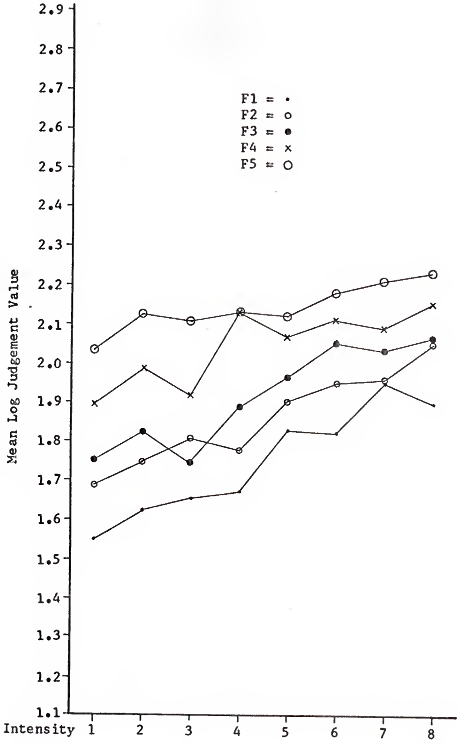


Figure 6. Task 3/Frequency/Intensity Interaction by Frequency

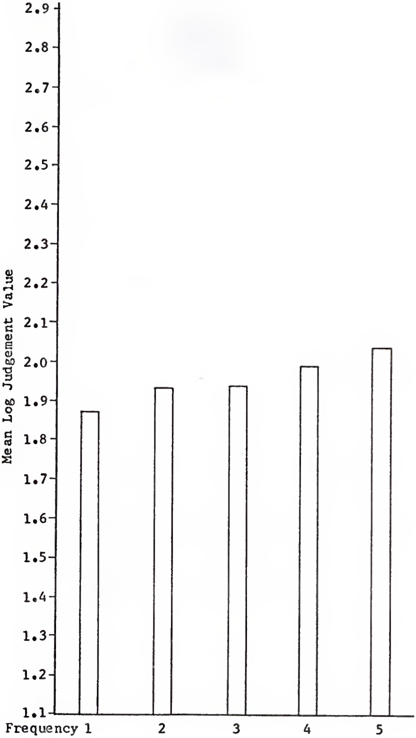


Figure 7. Frequency Main Effect

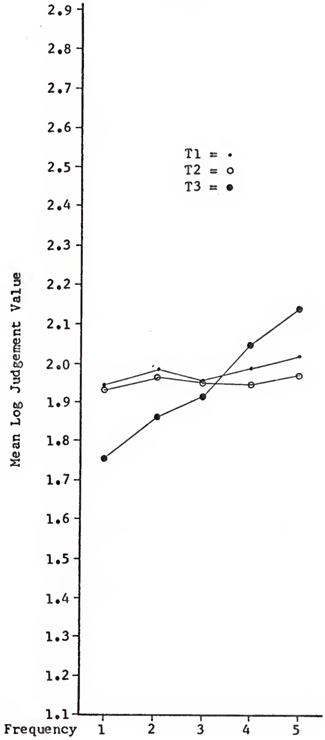


Figure 8. Task/Frequency Interaction by Task

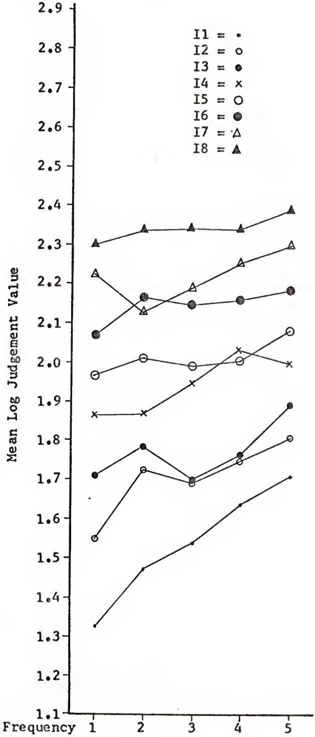


Figure 9. Frequency/Intensity Interaction by Intensity

that the low intensities are strongly influenced by frequency in a direct relationship while the highest intensity reflects almost nil influence. It is apparent, then, that frequency both influences (Figure 9) and is influenced by (Figure 6) intensity.

Order

Figure 10 clearly shows that order 3 (LPE) is well below the other orders in absolute value as apparent also in the mean data of Table 40 and the comparison data of Table 46. Individual inspection of the significant comparisons (Table 46) initially suggests that when the effort and loudness tasks are separated by the pitch task, hence separated in time by at least two days, the value of all judgements drops. Since order 2 also has pitch as the middle task and does not conform to this hypothesis, it appears to be invalid. In a similar manner, other suggestions have been eliminated by the non-concurrence of the ordering with the parallel condition (e.g., loudness preceeding pitch: order 1 does not conform with order 3; pitch preceeding effort: order 5 belies this). The writer is thus unable to offer an explanation for the observed order effects and can only suggest that it is a factor which requires extensive investigation as well as one which must be considered in any future research of a multiple-task nature.

Task

Task did not attain statistical separation (5% level of significance) at the main effect level. For completeness, however, the task mean data of Table 39 are provided graphically as Figure 11. While task 1 did generate the largest mean judgement value, it cannot be considered at the main effect level.

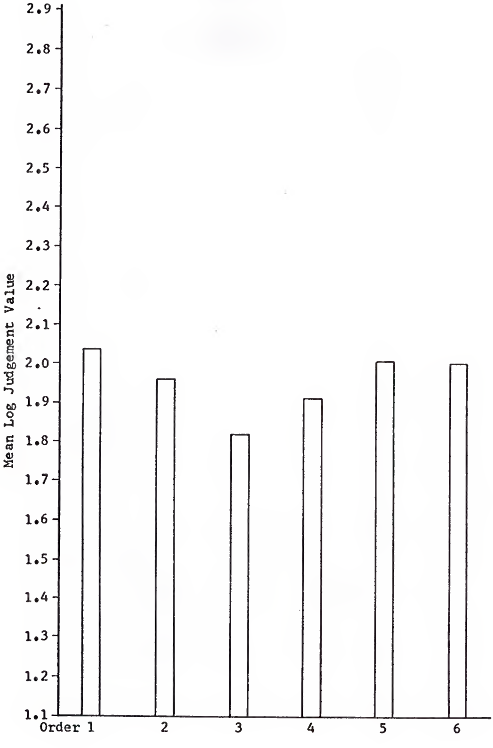


Figure 10. Order Main Effect

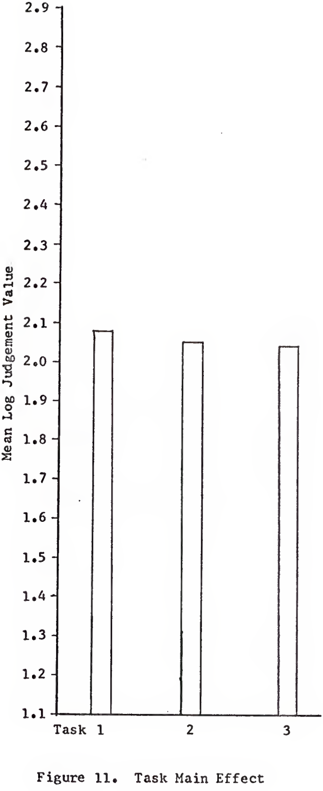


Figure 11. Task Main Effect

It is pertinent to note in Figure 5 (task/intensity interaction) that the loudness and effort tasks, while essentially identical, do differ statistically at the two lowest intensity levels (Table 32). The implication is that while effort judgements do follow intensity changes, they are depressed less by intensity lowering than are loudness judgements, i.e., that listeners are perceiving something that is not specifically or not solely loudness at the lowest intensities. It should be noted also that the effort and loudness judgements do significantly differ at the highest frequency level (Figure 8 and Table 38). Thus both intensity and frequency are seen to affect the effort judgement somewhat differently than the loudness judgement.

Examining the task/frequency/intensity interaction of Table 15, it becomes evident that the differential effect on tasks 1 and 2 occurs primarily at a combination of low intensity and high frequency. The task 1 portion of Table 15 is plotted as Figure 12 and shows clearly that the low intensity-high frequency combination raised the effort judgement. Also visible in Figure 12 (for effort) and in Table 16 (for both effort and loudness) is the general progression of F1 from being judged the least loud and least effortful at the low intensity to being judged loudest and most effortful at the high frequency. Statistical significance does not obtain throughout the progression but the trend is quite obvious.

Considering that frequency and intensity do covary directly when left uncontrolled, the lowest frequency-lowest intensity combination must be considered a reasonably normal production combination likely to be produced by a speaker without undue strain. Restricting the normal covariance as with the F1-I8 combination should introduce a

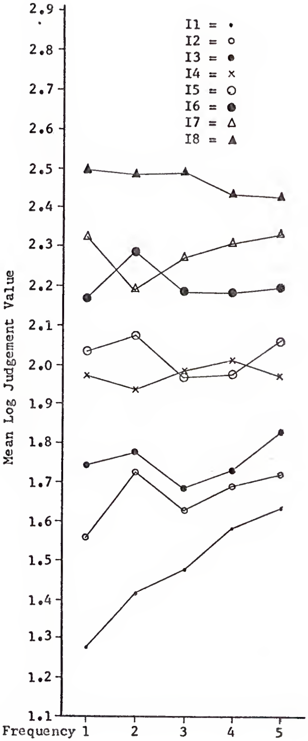


Figure 12. Task 1/Frequency/Intensity Interaction by Intensity

degree of strain into the production beyond that provided by the intensity increase alone. That F1 is judged more effortful than F2-5 at the I8 level would support this notion. Additionally, that F1 is judged louder than F2-5 at the I8 level suggests that the difference in production effort has influenced the loudness task as well. While the reciprocal notion, that F5 should be least effortful at I8, most effortful at I1, with a neat progression throughout, is imperfectly realized in Table 16, there is a slight trend to this effect. The writer tenders that F5 may be well below the actual frequency to be expected at the I8 (95 dB SPL) level were frequency and intensity allowed to covary. If this is reasonably correct, F5 of this study (196 Hz) may in fact be an appropriate frequency level for some intermediate intensity level, and cannot be expected to show true high-frequency performance. The above is, of course, a considerably suppositive interpretation.

Essentially, then, it appears from these results that listeners' judgements of effort are primarily based on their perception of the stimulus loudness, with a complex interaction between intensity and frequency occurring such that, at the lower intensities, frequency enters extensively into the effort judgement.

Stimuli Manipulations

Thus far the results have been presented and interpretation offered only for the condition of real F and real I (RR). As noted earlier, the present study also performed laboratory manipulations on the original stimuli to create four other blocks of presentation stimuli. These four manipulated conditions were RM (real F, equal I), MR (equal F, real I), MM (equal F, equal I) and AA (artificial F, artificial I). In terms of previous studies, the AA condition provides an equal-effort or equal-AL stimuli set while RM provides a varied-effort, constant intensity condition. There is no direct corollary to the equal-F manipulations (MR and MM) in the literature.

An analysis of variance was performed on each condition individually (as noted above, the four manipulated and the one real condition shared stimuli and were not truly independent and could not, therefore, be analyzed under a single design). Since the manipulations involved under the various conditions created a change in one or both experimental variables, it was not felt that a posteriori comparisons could be fruitfully performed. For example, to find a specific trend in the interaction of equalized-F with real-I would not appear to contribute to understanding the real-stimuli situation and such testing was not, therefore, considered relevant to the present investigation.

Results of the analyses and comparisons between conditions follow.

Tables 47-50 present the analysis of variance summaries for the manipulated conditions and Table 51 presents the significant (5% level of significance) results from all analyses including the analysis of the original (RR) stimuli as presented in Table 4.

Composite tables are presented from all conditions for I (Table 52), F (Table 53), O (Table 54) and T (Table 55) and these data are plotted, respectively, as Figures 13-16. It is obvious in Figure 13 that the removal of intensity differences (conditions RM and MM) tended to bring all judgement values closer to that of the standard, i.e., raised values for lower intensities and depressed values for higher intensities. At the lower intensities the RR and AA conditions differ markedly and the AA condition tends to be closer to the value of the

Table 47. Analysis of Variance Summary Table, RM

Source	Error Term	SS	df	MS	F
T(Task)	TS(0)	1.7726	2	0.8863	8.2413*
0(Order)	S(0)	9.8989	5	1.9798	4.8952*
F(Frequency)	SF(0)	2.2734	4	0.5683	16.5360*
I(Intensity)	SI(0)	6.4123	7	0.9160	18.6391*
S(0)(Subjects)		2.4266	6	0.4044	
TO	TS(0)	2.6040	10	0.2604	2.4212
TF	TSF(0)	4.7523	8	0.5940	25.2854*
OF	SF(0)	1.1996	20	0.0600	1.7451
TI	TSI(0)	0.2799	14	0.0200	1.5932
OI	SI(0)	0.8222	35	0.0235	0.4780
FI	SFI(0)	1.9225	28	0.0687	6.4162*
TS(0)		1.2905	12	0.1075	
SF(0)		0.8249	24	0.0344	
SI(0)		2.0641	42	0.0492	
TOF	TSF(0)	1.6853	40	0.0421	1.7934*
TOI	TSI(0)	1.0614	70	0.0152	1.2084
TFI	TSFI(0)	1.0478	56	0.0187	2.9366*
OFI	SFI(0)	1.8109	140	0.0129	1.2088
TSF(0)		1.1277	48	0.0235	
TSI(0)		1.0540	84	0.0125	
SFI(0)		1.7978	168	0.0107	
TOFI	TSFI(0)	1.8251	280	0.0065	1.0231
TSFI(0)		2.1407	336	0.0064	

*Significant at 5% level of significance

Table 48. Analysis of Variance Summary Table, MR

Source	Error Term	SS	df	MS	F
T(Task)	TS(0)	1.2955	2	0.6478	3.7582
O(Order)	S(0)	9.0317	5	1.8063	9.3018*
F(Frequency)	SF(0)	0.8987	4	0.2247	16.4749*
I(Intensity)	SI(0)	89.4090	7	12.7727	83.0146*
S(0)(Subjects)		1.1652	6	0.1942	
TO	TS(0)	2.6341	10	0.2634	1.5283
TF	TSF(0)	0.0604	8	0.0084	1.0432
OF	SF(0)	0.3105	20	0.0155	1.1386
TI	TSI(0)	16.1913	14	1.1565	28.2766*
OI	SI(0)	2.1597	35	0.0617	0.4011
FI	SFI(0)	2.0754	28	0.0741	8.8564*
TS(0)		2.0683	12	0.1724	
SF(0)		0.3273	24	0.0136	
SI(0)		6.4622	42	0.1539	
TOF	TSF(0)	0.2646	40	0.0066	0.8235
TOI	TSI(0)	6.3890	70	0.0913	2.2316*
TFI	TSFI(0)	0.6390	56	0.0114	1.6164*
OFI	SFI(0)	1.3544	140	0.0097	1.1560
TSF(0)		0.3856	48	0.0080	
TSI(0)		3.4356	84	0.0409	
SFI(0)		1.4060	168	0.0084	
TOFI	TSFI(0)	2.1085	280	0.0075	1.0667
TSFI(0)		2.3718	336	0.0071	

*Significant at 5% level of significance

Table 49. Analysis of Variance Summary Table, MM

Source	Error Term	SS	df	MS	F
T(Task)	TS(0)	4.4104	2	2.2052	12.5924*
O(Order)	S(0)	10.3314	5	2.0663	5.3508*
F(Frequency)	SF(0)	1.4670	4	0.3668	18.6548*
I(Intensity)	SI(0)	6.6078	7	0.9440	14.5912*
S(0)(Subjects)		2.3170	6	0.3862	
TO	TS(0)	4.1357	10	0.4136	2.3616
TF	TSF(0)	0.3482	8	0.0480	5.6612*
OF	SF(0)	0.2993	20	0.0150	0.7613
TI	TSI(0)	0.7673	14	0.0548	2.8041*
OI	SI(0)	0.9097	35	0.0260	0.4018
FI	SFI(0)	2.4158	28	0.0863	4.8432*
TS(0)		2.1014	12	0.1751	
SF(0)		0.4718	24	0.0197	
SI(0)		2.7171	42	0.0647	
TOF	TSF(0)	0.3274	40	0.0082	0.9647
TOI	TSI(0)	1.7424	70	0.0249	1.2736
TFI	TSFI(0)	1.5864	56	0.0283	2.0978*
OFI	SFI(0)	2.7182	140	0.0194	1.0899
TSF(0)		0.4072	48	0.0085	
TSI(0)		1.6417	84	0.0195	
SFI(0)		2.9929	168	0.0178	
TOFI	TSFI(0)	4.0697	280	0.0145	1.0763
TSFI(0)		4.5374	336	0.0135	

*Significant at 5% level of significance

Table 50. Analysis of Variance Summary Table, AA

Source	Error Term	SS	df	MS	F
T(Task)	TS(0)	0.8717	2	0.4358	2.2011
O(Order)	S(0)	10.0272	5	2.0054	17.0165*
F(Frequency)	SF(0)	3.5865	4	0.8966	22.6788*
I(Intensity)	SI(0)	47.4891	7	6.7842	49.2330*
S(0)(Subjects)		0.7071	6	0.1179	
TO	TS(0)	2.7711	10	0.2771	1.3995
TF	TSF(0)	4.8283	8	0.6035	22.6019*
OF	SF(0)	1.7551	20	0.0878	2.2196*
TI	TSI(0)	17.7371	14	1.2669	38.7050*
OI	SI(0)	1.4340	35	0.0424	0.3077
FI	SFI(0)	2.0338	28	0.0726	7.3507*
TS(0)		2.3760	12	0.1980	
SF(0)		0.9489	24	0.0395	
SI(0)		5.7875	42	0.1378	
TOF	TSF(0)	1.5123	40	0.0378	1.4159
TOI	TSI(0)	4.1426	70	0.0592	1.8080*
TFI	TSFI(0)	0.8944	56	0.0160	1.9653*
OFI	SFI(0)	1.4498	140	0.0104	1.0480
TSF(0)		1.2817	48	0.0267	
TSI(0)		2.7496	84	0.0327	
SFI(0)		1.6601	168	0.0100	
TOFI	TSFI(0)	2.3270	280	0.0083	1.0226
TSFI(0)		2.7306	336	0.0081	

*Significant at 5% level of significance

Table 51. Summary of Significant Effects, All Conditions

	RR	RM	MR	MM	AA
T		*		*	
O	*	*	*	*	*
F	*	*	*	*	*
I	*	*	*	*	*
TO					
TF	*	*		*	*
OF	*				*
TI	*		*	*	*
OI					
FI	*	*	*	*	*
TOF		*			
TOI	*		*		*
TFI	*	*	*	*	*
OFI					
TOFI					

*Significant at 5% level of significance

Table 52. Mean Log Judgements for Intensity, All Conditions

		Condition				
		RR	RM	MR	MM	AA
I	1	1.535	1.884	1.572	1.869	1.735
	2	1.701	1.879	1.714	1.961	1.838
	3	1.765	1.946	1.834	1.982	1.893
	4	1.941	1.984	1.947	2.018	1.984
	5	2.007	2.007	2.057	2.062	2.030
	6	2.142	2.045	2.163	2.046	2.126
	7	2.216	2.016	2.230	2.074	2.220
	8	2.338	2.074	2.348	2.084	2.303

Table 53. Mean Log Judgements for Frequency, All Conditions

		Condition				
		RR	RM	MR	MM	AA
F	1	1.874	1.946	2.009	2.037	2.031
	2	1.934	1.945	1.995	2.043	1.944
	3	1.940	1.954	1.940	1.954	1.981
	4	1.991	2.008	1.972	2.005	2.036
	5	2.040	2.044	2.000	2.021	2.089

Table 54. Mean Log Judgements for Order, All Conditions

		Condition				
		RR	RM	MR	MM	AA
O	1	2.035	2.076	2.084	2.123	2.100
	2	1.962	1.976	1.984	2.006	2.036
	3	1.818	1.814	1.834	1.850	1.849
	4	1.909	1.966	1.946	1.988	1.980
	5	2.008	2.002	2.038	2.038	2.076
	6	2.002	2.042	2.011	2.068	2.055

Table 55. Mean Log Judgements for Task, All Conditions

		Condition				
		RR	RM	MR	MM	AA
T	1	1.978	2.008	2.011	2.047	2.043
	2	1.949	2.000	1.997	2.055	2.022
	3	1.940	1.930	1.941	1.934	1.983

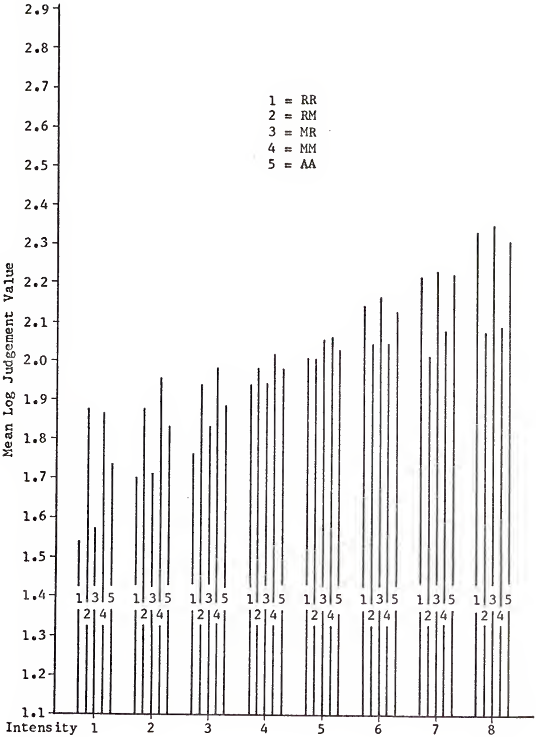


Figure 13. Intensity Main Effect, All Conditions

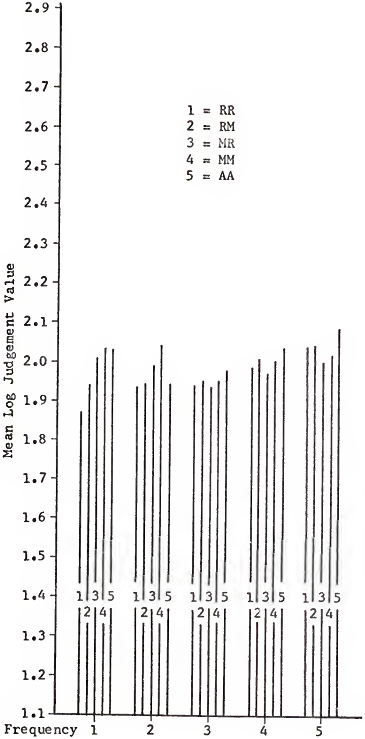


Figure 14. Frequency Main Effect, All Conditions

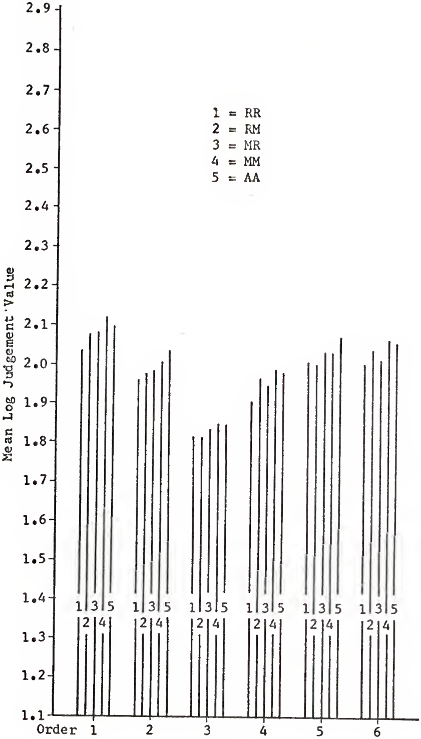


Figure 15. Order Main Effect, All Conditions

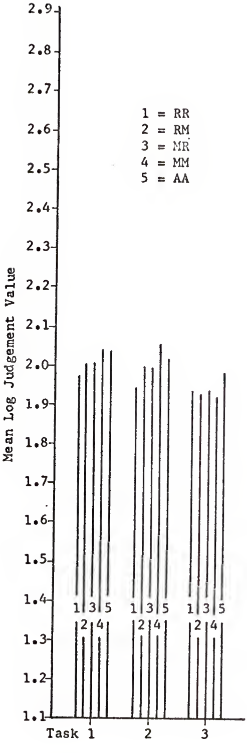


Figure 16. Task Main Effect, All Conditions

standard, i.e., is less influenced by intensity change. The MR condition shows little change from the RR condition and definitely evidences intensity influence.

In Figure 14 it may be seen that F1 was affected by all manipulations, F2 by the two frequency manipulations, F3 little affected by any change, F4 influenced most by the artificial situation and F5 most by the artificial and the frequency-only manipulation.

Throughout the manipulations, as visible in Figure 15, the effect on a given order is approximately the same as the effect on any other order, so that the order relationships are relatively constant within a condition. This constancy is apparent in Table 51, since order presents significance at the one-way level (5% level of significance) under all conditions. The order/frequency interaction significance disappears not only when frequency is removed (MR and MM) but also when intensity is removed (RM). The task/order/intensity interaction, however, is affected only by the intensity manipulations (RM and MM).

Task attained statistical significance (5% level of significance) in the two instances of intensity removal (RM and MM) as given in Table 51. It appears, as illustrated in Figure 16, that task significance is due primarily to the stability of task 3 under the intensity removal conditions while both tasks 1 and 2 were responsive to this change.

Since Table 51 shows the task/intensity interaction significance disappearing when intensity-only is removed (RM), composite mean data from all conditions for this interaction are presented in Table 56 and plotted as Figure 17 for task 1, as Figure 18 for task 2 and as Figure 19 for task 3 so that manipulation effects might be observed.

It appears that the removal of intensity cues, with or without

Table 56. Task/Intensity Interaction--Mean Log Judgement Values, All Conditions

Condition RR

		Intensity							
		1	2	3	4	5	6	7	8
T	1	1.476	1.662	1.749	1.974	2.019	2.201	2.282	2.466
	2	1.346	1.583	1.703	1.933	2.028	2.207	2.321	2.473
	3	1.782	1.858	1.844	1.916	1.974	2.019	2.046	2.076

Condition RM

		Intensity							
		1	2	3	4	5	6	7	8
T	1	1.927	1.930	1.970	2.018	2.019	2.069	2.035	2.096
	2	1.900	1.908	1.980	2.009	2.028	2.070	2.013	2.095
	3	1.825	1.799	1.889	1.926	1.974	1.995	2.001	2.029

Condition MR

		Intensity							
		1	2	3	4	5	6	7	8
T	1	1.511	1.692	1.821	1.975	2.077	2.215	2.318	2.479
	2	1.407	1.656	1.796	1.959	2.108	2.240	2.324	2.488
	3	1.798	1.794	1.887	1.908	1.985	2.035	2.048	2.078

Condition MM

		Intensity							
		1	2	3	4	5	6	7	8
T	1	1.916	2.012	2.009	2.046	2.093	2.060	2.120	2.119
	2	1.886	2.053	2.050	2.075	2.108	2.079	2.093	2.100
	3	1.804	1.819	1.887	1.934	1.985	1.999	2.009	2.034

Condition AA

		Intensity							
		1	2	3	4	5	6	7	8
T	1	1.684	1.800	1.869	2.002	2.042	2.184	2.321	2.439
	2	1.591	1.748	1.840	1.980	2.048	2.193	2.319	2.461
	3	1.929	1.965	1.969	1.971	2.000	2.002	2.020	2.010

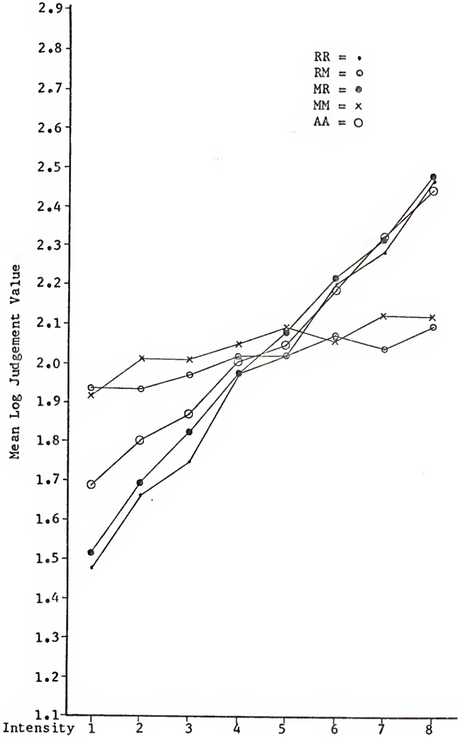


Figure 17. Task 1/Intensity Interaction, All Conditions

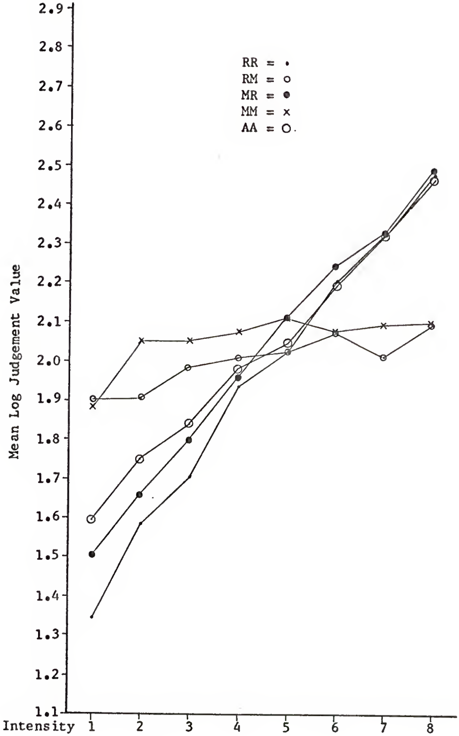


Figure 18. Task 2/Intensity Interaction, All Conditions

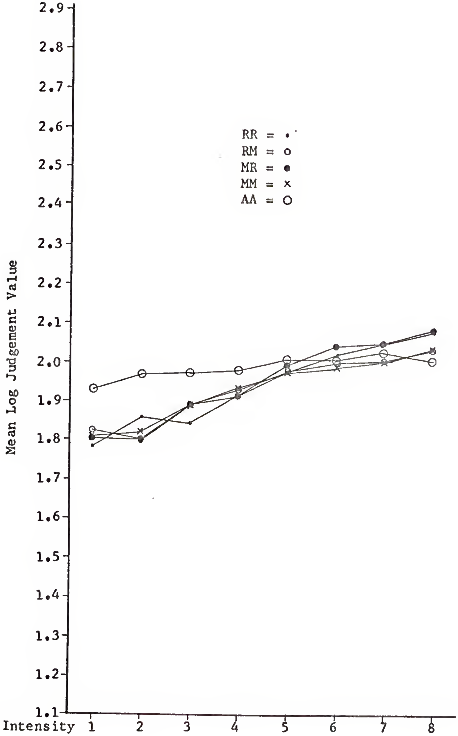


Figure 19. Task 3/Intensity Interaction, All Conditions

frequency equalization, is the effective manipulation for effort judgements as shown in Figure 17, with removal of frequency cues alone little affecting the effort judgement. There is evident, however, an influence by the AA condition at the lower intensity levels, suggesting that some element of the equal-effort situation is perceived by listeners.

Figure 18 shows that there was a similar tendency in the loudness judgements, both for removal of intensity cues to greatly depress the judged values and for the artificial stimuli values to be less depressed at the lower intensities than were the RR stimuli. Loudness judgements did evidence somewhat more effect from the removal of frequency cues (alone) than did effort judgements.

For task 3 there was little change in the influence of intensity as a result of manipulation except for the AA condition as may be seen in Figure 19. It appears that with task 3 as well as with the other tasks that the equal-effort aspect of the artificial stimuli was being perceived, albeit subtly in each case.

As a verification that listeners' performance did in fact reflect the frequency manipulation, the task/frequency interaction data from all conditions was composited as Table 57 and the task 3 data from this table plotted as Figure 20. It is evident that listener judgements did indeed change when frequency cues were removed. It should be noted too that while the AA condition generally was not greatly different from the RR or RM conditions, the AA judgement values tended to be higher than those for the other two conditions, markedly so at F1, suggesting that even pitch judgements were susceptible to influence by the equal-effort situation.

The implication from these manipulative results is that listeners

Table 57. Task/Frequency Interaction--Mean Log Judgement Values, All Conditions

Condition RR

		Frequency				
		1	2	3	4	5
T	1	1.944	1.984	1.959	1.987	2.019
	2	1.927	1.961	1.948	1.944	1.965
	3	1.750	1.857	1.913	2.041	2.136

Condition RM

		Frequency				
		1	2	3	4	5
T	1	2.032	1.993	1.967	2.012	2.035
	2	2.033	1.992	1.984	2.003	1.990
	3	1.774	1.850	1.910	2.011	2.105

Condition MR

		Frequency				
		1	2	3	4	5
T	1	2.041	2.025	1.959	2.004	2.026
	2	2.023	2.005	1.948	1.984	2.027
	3	1.964	1.956	1.913	1.928	1.947

Condition MM

		Frequency				
		1	2	3	4	5
T	1	2.068	2.090	1.968	2.048	2.061
	2	2.079	2.102	1.984	2.062	2.050
	3	1.964	1.938	1.910	1.906	1.953

Condition AA

		Frequency				
		1	2	3	4	5
T	1	2.118	1.997	1.989	2.023	2.086
	2	2.101	1.980	1.985	2.018	2.028
	3	1.873	1.854	1.969	2.067	2.154

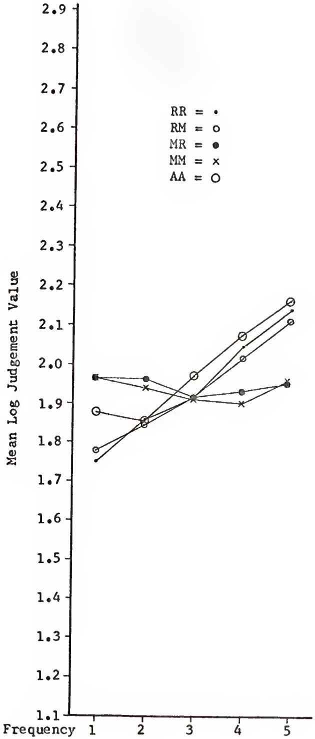


Figure 20. Task 3/Frequency Interaction, All Conditions

essentially equate loudness and effort but that they do perceive some aspect of the vocal effort involved in the sample production, although the influence of vocal effort on the judgement is mostly restricted to the lower intensity stimuli.

Discussion of the Research Questions

The present study was conducted to determine whether the magnitude estimates made by listeners of vocal samples differed when they judged for (1) effort, (2) loudness and (3) pitch. Additionally, the study attempted to determine the effect of vocal fundamental frequency and vocal intensity on these judgements.

The results of the current study, as presented in the preceeding sections, indicate that listener judgements of pitch differ from judgements of both effort and loudness, but that judgements of effort and judgements of loudness are essentially the same. In other words, it is indicated that a listener takes his perception of loudness to be a percept of effort, in the main. An interaction between frequency and intensity was noted, however, such that for the low intensity-high frequency stimuli, judgements of effort and loudness statistically (5% level of significance) differed. Consequently it is only partially correct to equate effort and loudness percepts. Also found in the present study was a significant order-of-task-presentation effect. The writer is unable to explain or interpret this order finding but suggests that it be given serious attention for future research.

Because the previous research has been reported in terms of the judgement-magnitude-estimates vs. SPL slope, data from the present study have been subjected to a least squares linear regression determination of slope and the slope values plotted as Figure 21. Figure 22 is a slope-graphing of all previous production studies (or the production portions of a study) with Stevens' (1955) loudness vs SPL determination included as a base reference. This figure represents what Lane, Catania and Stevens (1961) referred to as autophonic level (AL).

In the single study (Moll and Peterson, 1969) to report production estimates by f_o level, a considerable difference was noted between the slopes for the four f_o levels. Figure 23 presents these data. It may be noted that the lowest f_o (125 Hz) yielded the steepest slope although there is no linear progression over the f_o range.

Moll and Peterson (1969) reported their listener loudness judgements by f_o also and Figure 24 presents these data as well as the loudness data from the present study. While Moll and Peterson's listeners showed a steepening slope as f_o increased, listeners in the present study evidenced essentially equivalent slopes for all f_os but the lowest (123 Hz). The listener slope for 123 Hz in the present study is more comparable to the speaker slope of Figure 23 for the 125 or 350 Hz level.

Figure 25 composites all listener judgement slopes for loudness from the previous studies and includes the current study. It may be seen that the slope value of the present study reasonably well agrees with the findings of Moll and Peterson (1969), Hixon, Minifie and Tait (1967), Lane, Catania and Stevens (1961) and Warren, Sersen and Pores (1958). The finding of the present study is well in excess of the slopes noted by Lane (1962) or Pollack (1952) and well below those found by Mendel _et al_. (1969), Brandt, Ruder and Shipp (1969) and Ladefoged and McKinney (1963).

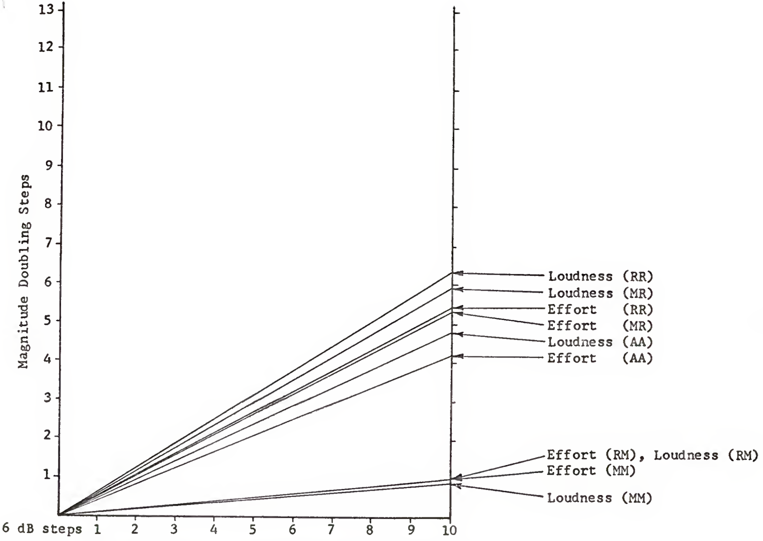


Figure 21. Listener Loudness vs SPL and Listener Effort vs SPL Slopes: All Conditions

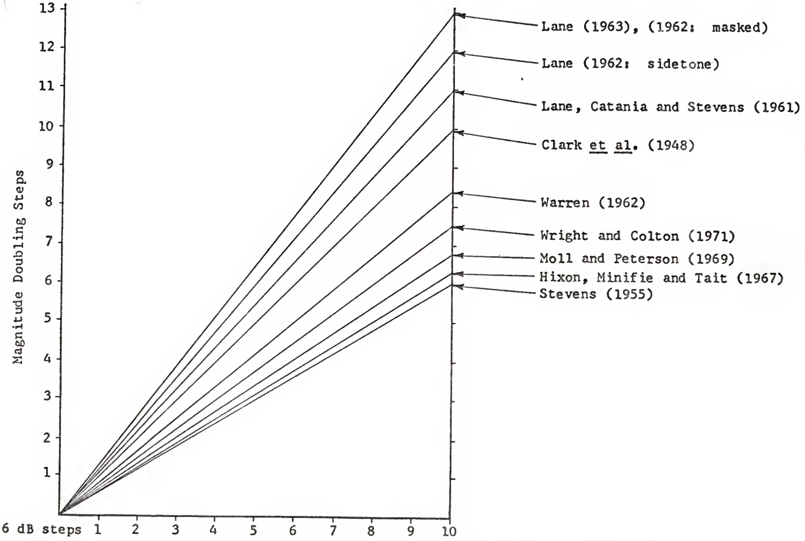


Figure 22. Speaker Loudness vs SPL Slopes: All Studies

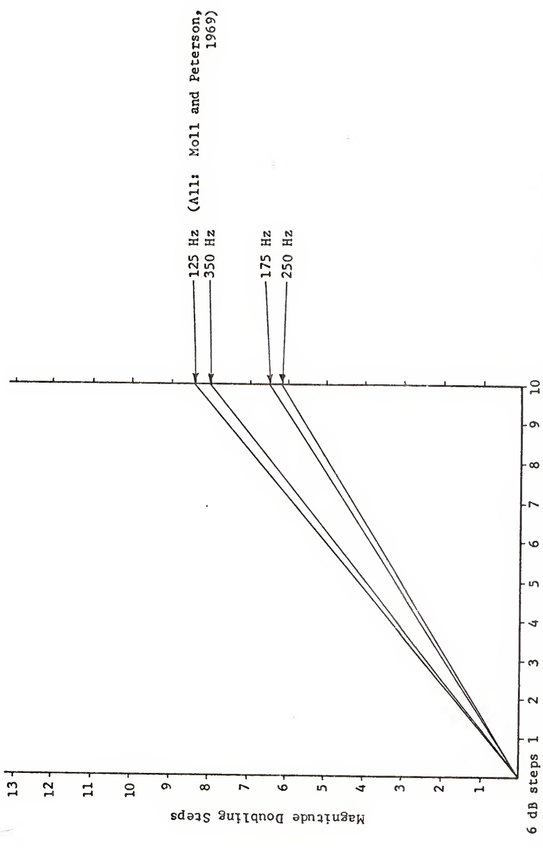


Figure 23. Speaker Loudness vs SPL Slopes by Fundamental Frequency

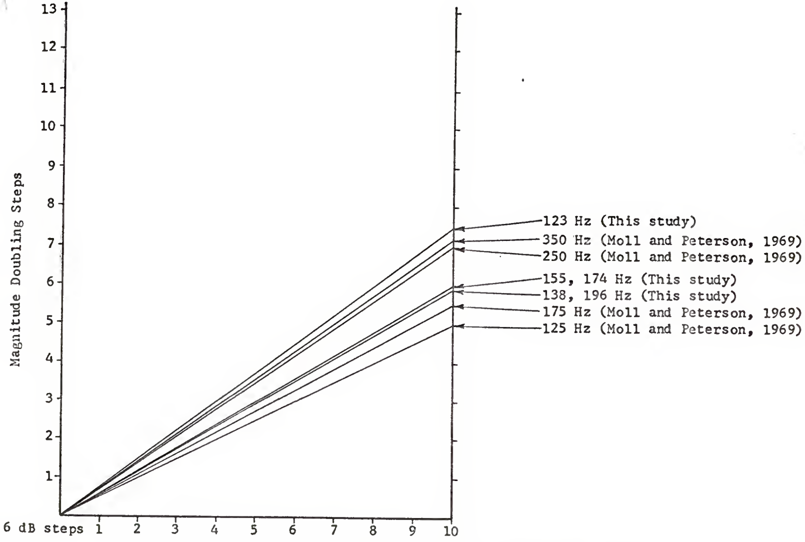


Figure 24. Listener Loudness vs SPL by Fundamental Frequency

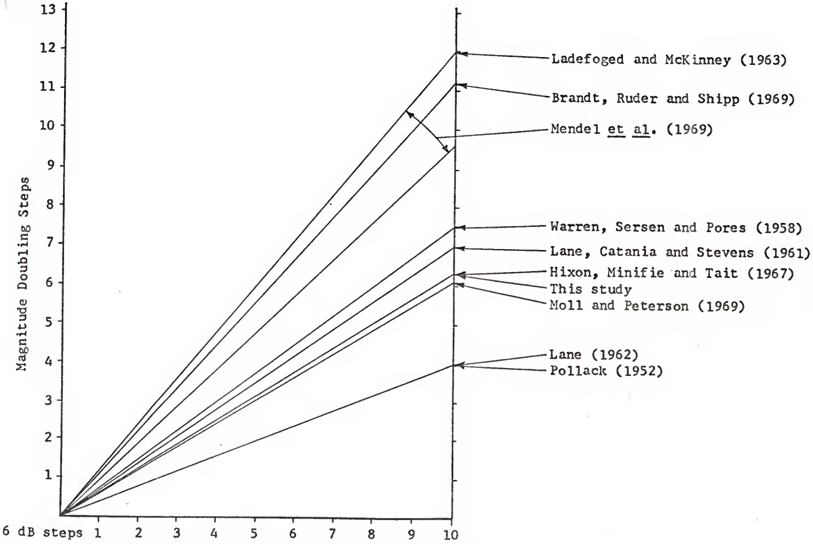


Figure 25. Listener Loudness vs SPL Slopes: All Studies

In Figure 26 the loudness judgement slopes from all studies which introduced any stimuli manipulation have been plotted. The data from the present study does not include that from a frequency manipulation since there is no comparable manipulation in the previous research. While the values from the present study are well below those found by Brandt, Ruder and Shipp (1969) for comparable manipulations, they agree quite well with Brandt's (1972a) findings under the filtering condition in spite of the stimuli difference--vowel excerpts in the present study vs sentential stimuli in Brandt. The present study does not agree well with Mendel et al. (1969) who showed steeper slopes, or with Lane (1962) whose slope was steeper for all but the equal-intensity, varied-effort condition (RM) of the present study.

The findings of the current study generally lie somewhat medial to the findings reported by other researchers, with the loudness slope for the RR (real stimuli) condition being essentially the same as the 0.6 value derived by Stevens (1955) and utilized since that time as a standard for the loudness vs. SPL relationship.

The present study has yielded some additional information about the judgement of effort, however, having found that while the judgement was primarily based on the loudness percept, the fundamental frequency of the stimulus did contribute to the effort percept, somewhat mitigating the effects of loudness at the lower intensity levels. The present study also found indication that vocal effort tends to influence the percepts of both loudness and pitch, somewhat modifying intensity effects.

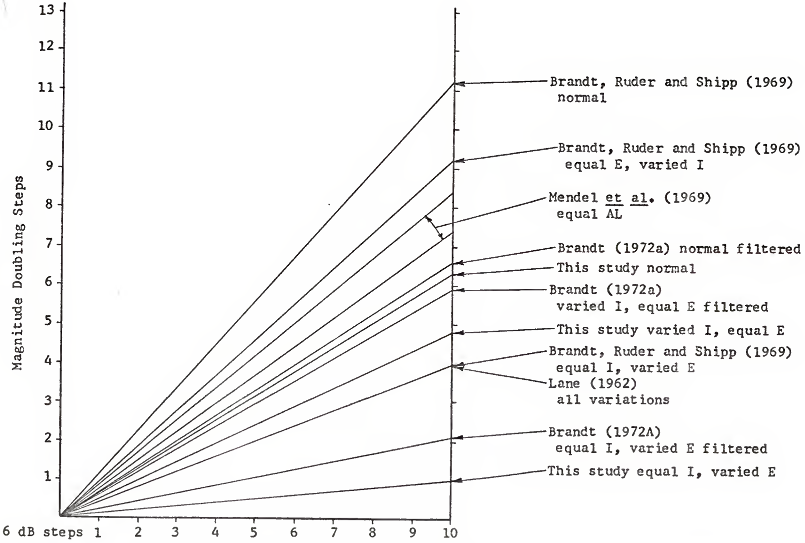


Figure 26. Listener Loudness vs SPL Slopes: All Manipulation Studies

IV

SUMMARY AND CONCLUSIONS

Sustained vowel production samples were utilized in the present study as stimuli for listener judgement of effort, loudness and pitch in an attempt to determine whether the three tasks yielded different judgement values, i.e., whether the listener percepts of effort, loudness and pitch differed. In order to examine for the contribution of vocal fundamental frequency (f_o) and vocal intensity to the effort percept, one male speaker produced vocal samples at five f_{os} at each of eight intensity levels. After validation of the 40 samples they were subjected to laboratory manipulation to provide, in addition to the actual stimuli with controlled f_o and intensity, four other 40-stimuli blocks wherein (1) f_o varied while intensity did not, (2) f_o did not vary while intensity did, (3) neither f_o nor intensity varied and (4) both f_o and intensity levels were artificially created from a single production sample. After electronic processing to excerpt a shaped, constant-duration sample from each production, stimuli from the five blocks were randomized onto a presentation tape recording. The stimuli were presented to the better ear of each of 12 listeners via earphones in a sound treated room, at 60-95 dB SL, following an audiometric test and qualification. Each listener performed all three judgement tasks, with two listeners assigned to each of the six possible orderings. Statistical analyses were performed on these judgement data.

The results of the analyses indicated that while both f_0 and intensity contributed to all judged values, the pitch judgements resulted primarily from f_0 and the loudness and effort judgements primarily from intensity. An intensity/f_0 interaction was found such that the two parameters did not operate independently on any task. Consequently, intensity did influence the pitch task to a degree and f_0 was found, particularly at the high f_0-low intensity levels, to influence the loudness and effort tasks. While the effort and loudness judgements were found to be essentially equal, they were found to be statistically different at the lower intensities, with effort judgements being larger. Thus, while listeners did appear to have based their effort judgements primarily on the perceived loudness of the stimuli, this correspondence diminished at low intensities so that, at these extremely low intensity levels, and particularly for the higher frequencies, the percepts of effort and loudness were indeed different.

Analysis of the manipulative conditions was found to support the findings above, with removal of f_0 cues severely reducing pitch judgements and removal of intensity cues severely restricting both effort and loudness judgements. The intensity/f_0 interaction was found to be statistically significant over all manipulations, however, further validating the non-independence of the two parameters.

Based primarily on graphical interpretation of the data, it was noted that the equal-effort situation existing in the artificially-created samples appeared to influence all task judgements, suggesting that listeners, while not generally differentiating between loudness and effort, did indeed perceive and respond to some factor of the signal related to effort. Since the artificial samples presented the same range of f_o and intensity variation as did the other stimuli blocks, the only essential difference lies in their representing but a single effort level.

It was found also that there was a significant order-of-task-presentation effect, both at the main effect level and at interactive levels. The main effect and several of the interactions obtained over all conditions of stimuli manipulation. The author was unable to detect sufficient pattern in the order effects to tender any explanation and can only suggest that task ordering be given serious consideration in planning future multiple-task research. It is further suggested that order be investigated in detail toward determining the exact influence of this factor.

Insofar as previous studies were similar to the present study, comparisons were made and the results of the present study were found to be not greatly divergent from other findings, with the present results lying generally in the medial range of all findings.

The finding in the present study that both parameters--f_o and intensity--contribute to judgement of effort suggests that additional investigation be made toward a better delimitation of the contribution made by f_o. Since a marked f_o influence was noted with a high f_o-low intensity combination, it would presumably be productive to expand the f_o range utilized as greatly as possible (within the modal register) while maintaining as large an intensity range as can be produced by the speaker. The one-tone steps utilized in the present study appear to be reasonable f_o increments.

Based on the findings of the current study--those from the original study being verified by the manipulative conditions-- it is suggested that laboratory manipulation of the stimuli be temporarily foregone in favor of the expanded stimulus matrix suggested above. It is further suggested that the pitch task be eliminated and that, until the exact nature of the task-ordering factor is known, listeners be subjected to only the single task ordering of either loudness-effort or effort-loudness.

While the present study dealt intentionally with naive listeners and found that they appeared to have little difficulty in either comprehending or performing the required tasks, it was noted that some listeners tended to be much more consistent in their judgements from repetition to repetition. In view of this the future researcher would be well advised to (1) select listeners carefully or (2) train listeners to some consistency criterion toward eliciting more detailed information about the percept, effort.

Appendix A

Listener Instructions

Listener Instructions

The following instructions were given each prospective listener in typewritten form, accompanied by one of the three pages following, also in typewritten form, according to the initial task. The applicant was advised that these were the actual experimental instructions and that he was to disregard the reference to one hour being required. He was informed that the qualification session would require only 15-20 minutes total.

The instructions below and the appropriate task page (following) were placed on the table in the experimental room prior to a listener's experimental session and remained in view throughout the session. The listener was requested to review the instructions prior to each task.

During the next hour you will be presented a series of vocal samples, all representing the phoneme /ɛ/ (the sound of the vowel in the word neck). These samples have been produced by a single speaker under a variety of experimental conditions and may appear to be different phonemes produced by different speakers. Since your task does not involve identification of either the speaker or the phoneme, your attention should not be directed to either factor.

One hour should be adequate for the experimental procedure. If you do not have the full hour available at this time, please advise the experimenter so that he may reschedule you since the entire presentation must be completed at a single session.

Samples are regularly spaced and you should not feel rushed. A pause (approximately 12 seconds) is provided after each 25 samples. Three answer sheets are used, one for each of three tapes, and during the time while the experimenter changes tapes you may remove the headphones. Your listening time is 16-17 minutes for each tape.

Your specific task differs during the three sessions. A separate sheet details the task for each session. Be sure to schedule your next session with the experimenter before leaving.

Effort Task Instructions

Your task for this session is to judge the vocal samples in terms of EFFORT. When you hear the word "standard" on the tape, you are to assign a numerical value to the sample following, a sample which is being used as a reference level. This numerical value is to be written in the answer sheet blank labeled "S."

The number you select for the reference sample, i.e., the "standard" is completely up to you. Pick a value which you feel is appropriate for the EFFORT represented by the sample.

You will then judge all vocal samples in terms of how they relate to the reference level. If a sample seems to you to represent twice as much EFFORT, you would write in the appropriate blank a number twice as large as your reference number. If 4 times the EFFORT, a number 4 times as large. If 1/5 the EFFORT, write a number 1/5 the value of your reference.

There is no minimum or maximum value intended. The only restriction is that you are not permitted to use the value zero. Do not attempt to scale the values between, say, 1 and 10 or 1 and 100. If you choose 50, for example, as your reference level, and restrict yourself to numbers between 1 and 100, you cannot indicate that a sample is judged 3 or 4 or 8 times greater in EFFORT. In other words, what is desired is numbers that reflect what you feel to be the ratio between each sample and the reference level.

If you are comfortable with fractions or decimals or powers of ten, feel free to select these numbers. If whole numbers are more comfortable for you, use whole numbers.

Sample presentation order is: the word, "standard"
the reference sample
25 samples to be judged
the word, "standard"
the reference sample
25 samples to be judged

. . .

(see answer sheet)

Remember that there is a pause at the end of each 25 samples, i.e., before the word "standard."

Loudness Task Instructions

Your task for this session is to judge the vocal samples in terms of LOUDNESS. When you hear the word "standard" on the tape, you are to assign a numerical value to the sample following, a sample which is being used as a reference level. This numerical value is to be written in the answer sheet blank labeled "S."

The number you select for the reference sample, i.e., the "standard" is completely up to you. Pick a value which you feel is appropriate for the LOUDNESS represented by the sample.

You will then judge all vocal samples in terms of how they relate to the reference level. If a sample seems to you to represent twice as much LOUDNESS, you would write in the appropriate blank a number twice as large as your reference number. If 4 times the LOUDNESS, a number 4 times as large. If 1/5 the LOUDNESS, write a number 1/5 the value of your reference.

There is no minimum or maximum value intended. The only restriction is that you are not permitted to use the value zero. Do not attempt to scale the values between, say, 1 and 10 or 1 and 100. If you choose 50, for example, as your reference level, and restrict yourself to numbers between 1 and 100, you cannot indicate that a sample is judged 3 or 4 or 8 times greater in LOUDNESS. In other words, what is desired is numbers that reflect what you feel to be the ratio between each sample and the reference level.

If you are comfortable with fractions or decimals or powers of ten, feel free to select these numbers. If whole numbers are more comfortable for you, use whole numbers.

Sample presentation order is: the word, "standard"
the reference sample
25 samples to be judged
the word, "standard"
the reference sample
25 samples to be judged

. . .

(see answer sheet)

Remember that there is a pause at the end of each 25 samples, i.e., before the word "standard."

Pitch Task Instructions

Your task for this session is to judge the vocal samples in terms of PITCH. When you hear the word "standard" on the tape, you are to assign a numerical value to the sample following, a sample which is being used as a reference level. This numerical value is to be written in the answer sheet blank labeled "S."

The number you select for the reference sample, i.e., the "standard" is completely up to you. Pick a value which you feel is appropriate for the PITCH represented by the sample.

You will then judge all vocal samples in terms of how they relate to the reference level. If a sample seems to you to represent twice as much PITCH, you would write in the appropriate blank a number twice as large as your reference number. If 4 times the PITCH, a number 4 times as large. If 1/5 the PITCH, write a number 1/5 the value of your reference.

There is no minimum or maximum value intended. The only restriction is that you are not permitted to use the value zero. Do not attempt to scale the values between, say, 1 and 10 or 1 and 100. If you choose 50, for example, as your reference level, and restrict yourself to numbers between 1 and 100, you cannot indicate that a sample is judged 3 or 4 or 8 times greater in PITCH. In other words, what is desired is numbers that reflect what you feel to be the ratio between each sample and the reference level.

If you are comfortable with fractions or decimals or powers of ten, feel free to select these numbers. If whole numbers are more comfortable for you, use whole numbers.

Sample presentation order is: the word, "standard"
the reference sample
25 samples to be judged
the word, "standard"
the reference sample
25 samples to be judged

. . .

(see answer sheet)

Remember that there is a pause at the end of each 25 samples, i.e., before the word "standard."

Appendix B

Listener Response Sheet

Listener Response Sheet

NAME____ TASK________________

ADDRESS____ DATE__________

S__________
1__________
2__________
3__________
4__________
5__________
6__________
7__________
8__________
9__________
10__________
11__________
12__________
13__________
14__________
15__________
16__________
17__________
18__________
19__________
20__________
21__________
22__________
23__________
24__________
25__________

S__________
26__________
27__________
28__________
29__________
30__________
31__________
32__________
33__________
34__________
35__________
36__________
37__________
38__________
39__________
40__________
41__________
42__________
43__________
44__________
45__________
46__________
47__________
48__________
49__________
50__________

S__________
51__________
52__________
53__________
54__________
55__________
56__________
57__________
58__________
59__________
60__________
61__________
62__________
63__________
64__________
65__________
66__________
67__________
68__________
69__________
70__________
71__________
72__________
73__________
74__________
75__________

S__________
76__________
77__________
78__________
79__________
80__________
81__________
82__________
83__________
84__________
85__________
86__________
87__________
88__________
89__________
90__________
91__________
92__________
93__________
94__________
95__________
96__________
97__________
98__________
99__________
100__________

S__________
101__________
102__________
103__________
104__________
105__________
106__________
107__________
108__________
109__________
110__________
111__________
112__________
113__________
114__________
115__________
116__________
117__________
118__________
119__________
120__________
121__________
122__________
123__________
124__________
125__________

S__________
126__________
127__________
128__________
129__________
130__________
131__________
132__________
133__________
134__________
135__________
136__________
137__________
138__________
139__________
140__________
141__________
142__________
143__________
144__________
145__________
146__________
147__________
148__________
149__________
150__________

S__________
151__________
152__________
153__________
154__________
155__________
156__________
157__________
158__________
159__________
160__________
161__________
162__________
163__________
164__________
165__________
166__________
167__________
168__________
169__________
170__________
171__________
172__________
173__________
174__________
175__________

BIBLIOGRAPHY

Allen, E.L. (1972). Perceptual and Acoustic Analyses of Selected Voice and Resonance Qualities. (Ph.D. Dissertation, Univ. of Florida, Gainesville.

Allen, G.D. (1971). "Acoustic level and vocal effort as cues for the loudness of speech," J. Acoust. Soc. Amer. 49, 1831-41.

Brandt, J.F. (1972a). "Effects of stimulus bandwidth on listener judgements of vocal loudness and effort," J. Acoust. Soc. Amer. 52, 705-7.

______ (1972b). "Listener perception of the fundamental frequency of continuous speech," paper presented at American Speech and Hearing Association Meetings.

______, Ruder, K.F. and Shipp, T. Jr. (1969). "Vocal loudness and effort in continuous speech," J. Acoust. Soc. Amer. 46, 1543-8.

Brown, W.S. Jr. (1972). personal communication.

Clark, K.C., Rudmose, H.W., Eisenstein, J.C., Carlson, F.D. and Walker, R.A. (1948). "The effects of high altitude on speech," J. Acoust. Soc. Amer. 20, 776-86.

Colton, R.H. and Brown, W.S. Jr. (1972). "Some relationships between vocal effort and intra-oral air pressure," paper presented at 84th Meeting of the Acoustical Society of America.

Fairbanks, G. and Miron, M.S. (1957). "Effects of vocal effort upon the consonant-vowel ratio within the syllable," J. Acoust. Soc. Amer. 29, 621-6.

Harrington, W.D. (1973). "Power hybrid circuit controls tape-recorder speed," Electronics. 46, No. 14, 108.

Hellman, R.P. and Zwislocki, J.J. (1961). "Some factors affecting the estimation of loudness," J. Acoust. Soc. Amer. 33, 687-94.

______ and Zwislocki, J.J. (1963). "Monaural loudness function at 1000 cps and interaural summation," J. Acoust. Soc. Amer. 35, 856-65.

Hixon, T.J., Minifie, F.D. and Tait, C.A. (1967). "Correlates of turbulent noise production for speech," J. Speech and Hearing Res. 10, 133-40.

Iles, R.L. (1972). *The Effect of Phonetic Environment on Lingual Pressure During Speech Production.* (M.A. Thesis, Univ. of Florida, Gainesville).

Jones, S. (1932). "The accent in French--what is accent?" Le Maitre Phonetique *40*, 74-5.

Joos, M. (1948). "Acoustic phonetics," Lang. Monographs *24*, No. 2, Suppl. 1-136.

Kirk, R.E. (1968). *Experimental Design: Procedures for the Behavioral Sciences* (Brooks-Cole, Belmont, California).

Ladefoged, P. and McKinney, N.P. (1963). "Loudness, sound pressure, and subglottal pressure in speech," J. Acoust. Soc. Amer. *35*, 454-60.

Lane, H. (1962). "Psychophysical parameters of vowel perception," Psychol. Monogr. *76*, No. 44, 1-25 (Whole No. 563).

______ (1963). "The autophonic scale of voice level for congenitally deaf subjects," J. Exp. Psych. *66*, 328-31.

______ (1965). "The motor theory of speech perception: a critical review," Psychol. Rev. *72*, 275-309.

______, Catania, A.C. and Stevens, S.S. (1961). "Voice level: autophonic scale, perceived loudness, and effects of sidetone," J. Acoust. Soc. Amer. *33*, 160-7.

Lehiste, I. and Peterson, G.E. (1959). "Vowel amplitude and phonemic stress in American English," J. Acoust. Soc. Amer. *31*, 428-35.

Liberman, A.M. (1957). "Some results of research on speech perception," J. Acoust. Soc. Amer. *29*, 117-23.

Mendel, M.I., Sussman, H.M., Mersen, R.M., Naeser, M.A. and Minifie, F.D. (1969). "Loudness judgements of speech and nonspeech stimuli," J. Acoust. Soc. Amer. *46*, 1556-61.

Moll, K.L. and Peterson, G.E. (1969). "Speaker and listener judgements of vocal levels," Phonetica *19*, 104-17.

Pickett, J.M. (1956). "Effects of vocal force on the intelligibility of speech sounds," J. Acoust. Soc. Amer. *28*, 902-5.

Pollack, I. (1952). "On the measurement of the loudness of speech," J. Acoust. Soc. Amer. *24*, 323-4.

Prebor, L.D. (1970). *Differences in Voice Quality as a Function of Interpersonal Distance and Sex of the Speaker-Sex of the Listener.* (M.A. Thesis, Univ. of Florida, Gainesville).

Stevens, S.S. (1955). "The measurement of loudness," J. Acoust. Soc. Amer. 27, 815-29.

Warren, R.M. (1962). "Are 'autophonic' judgements based on loudness?" Amer. J. Psychol. 75, 452-6.

______ (1963). "Are loudness judgements based on distance estimates?" J. Acoust. Soc. Amer. 35, 613-4.

______, Sersen, E.A. and Pores, E.B. (1958). "A basis for loudness judgements," Amer. J. Psychol. 71, 700-9.

Wright, H.N. (1965). "Is there a standard loudness?" J. Acoust. Soc. Amer. 37, 1175(A).

______ and Colton, R.H. (1971). "Some parameters of vocal effort," paper presented at 80th Meeting of the Acoustical Society of America.

______ and Colton, R.H. (1972). "Some parameters of autophonic level," paper presented at American Speech and Hearing Association Meetings.

BIOGRAPHICAL SKETCH

Robert Louis Iles was born November 15, 1936, at Bridgeport, Connecticut. He graduated from Central High School in June, 1954. From 1955 to 1958 he served with the United States Army Signal Corps, stationed primarily in East Africa. During 1958 and 1959 he attended the University of Tennessee at Knoxville. He held a variety of positions during the period 1958-1968, including carpenter, draftsman, salesman and fireman. Concurrently, during 1965 and 1966, he attended the University of South Florida at Tampa. In September, 1968, he enrolled in the University of Florida, Gainesville, and pursued a program leading to the Bachelor of Arts degree in Speech in June, 1970. On that date he entered the Graduate School at the University of Florida and continued his work in Speech, receiving the Master of Arts degree in Speech in March, 1972. Since that time Mr. Iles has studied for the degree of Doctor of Philosophy in the Communications Sciences Laboratory, Department of Speech.

Mr. Iles is married to the former Mallory Wallace.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

G. Paul Moore

G. Paul Moore, Chairman
Professor of Speech

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

E C Hutchinson

Edward C. Hutchinson
Associate Professor of Speech

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Donald W. Nielsen
Assistant Professor of Speech

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Madelaine M. Ramey

Madelaine M. Ramey
Assistant Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William A. Yost

William A. Yost
Assistant Professor of Speech

This dissertation was submitted to the Department of Speech in the College of Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1973

Dean, Graduate School